Spring 1-1-2011

The Relationship between Seismic Hazard Vulnerability and Stage of Economic Development: Illustration for Three Countries

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Recommended Citation

Nguyen, Lan T., "The Relationship between Seismic Hazard Vulnerability and Stage of Economic Development: Illustration for Three Countries" (2011). *Civil Engineering Graduate Theses & Dissertations*. 17.
https://scholar.colorado.edu/cven_gradetds/17

THE RELATIONSHIP BETWEEN SEISMIC HAZARD VULNERABILITY AND STAGE OF ECONOMIC DEVELOPMENT:

ILLUSTRATION FOR THREE COUNTRIES

by

LAN NGUYEN

B.S. University of Colorado at Boulder, 2009

A thesis submitted to the

Faculty of the Graduate School of the

University of Colorado in partial fulfillment

of the requirement for the degree of

Master of Engineering

In Civil Engineer

(Structures)

Department of Civil Engineering

University of Colorado at Boulder, CO

March, 2011

This thesis entitled:

The Relationship between Seismic Hazard Vulnerability and Stage of Economic Development: Illustration for Three Countries

Written by Lan Nguyen

Has been approved for the Department of Civil, Environmental and Architectural Engineering

(Ross Corotis)

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Date_______________

The final copy of this thesis has been examined by the signatories, and we
Find that both the content and the form meet acceptable presentation standards
Of scholarly work in the above mentioned discipline.

Abstract

Lan Nguyen (M.S. , Department of Civil, Environmental and Architectural Engineering)

THE RELATIONSHIP BETWEEN SEISMIC HAZARD VULNERABILITY AND STAGE OF ECONOMIC DEVELOPMENT: ILLUSTRATION FOR THREE COUNTRIES.

Thesis directed by Associate Professor Ross B. Corotis.

This thesis investigates the underlying relationship between the implicit level of risk accepted for natural hazard vulnerability, and the level of economic, social and political development of the country. In particular, it reports on a study of seismic hazard and code development/enforcement for three countries at very different levels of development, illustrated through a case study. Haiti, Chile, and New Zealand all experienced major earthquakes in 2010. The loss of life and devastation in Haiti, however, was much worse than in Chile and New Zealand, despite the magnitude of the earthquake being smaller.

The aim of this study is to compare the differences among the three events, as well as comment on some of the social aspects that led to the conditions at the time of the earthquakes. Variables considered are: magnitude of earthquake, depth of hypocenter, local geological conditions, demographics of the population, population at risk in the area of the earthquake, and performance of structures in the affected areas. Vulnerability information is also related to the seismic provisions of the building codes, and the atmosphere of code enforcement. Damage has been and is continuing to be investigated by several countries concerning the loss of lives, injury, property damage, and how well various structures have performed in these three countries.

This study reports on the connection between the performance of structures and the quality and enforcement of existing building codes in the respective countries. This is accomplished through a review of current and prior building codes, a comparison of the codes to that of the United States, and the standard practice of inspection or enforcement of codes during construction. Recognizing the differing degree of economic development and societal needs, and considering the international contributions of aid, the question of mandatory code development and enforcement is considered.

Acknowledge

I was very fortunate to have the support and encouragement from my advisor, Professor Corotis. I would like to thank him for sharing with me his insights into and enthusiasm for engineering involvement in such events, his willingness to be available at anytime I needed, and his most valuable sense of humor that created such a delightful environment to work with.

I would also like to thank Professor Guido Camata and Professor Enrico Spacone, from PRICOS Department, University of Chieti-Pescara, Italy, for their help and support. I am grateful for the opportunity to be their student. I am continually inspired by their commitment to their research and their teaching.

I have had an opportunity to work closely with a number of people outside of CU Boulder, Professor Jennifer Tanner from the University of Wyoming, Professor Mark Eberhard from University of Washington, and Professor Reginald Deroches from the Georgia Institute of Technology. I had an opportunity to know them and continuously got help from them, their suggestions have been very helpful in the development of this work. I also have had a benefited from discussion with Mr. James Harris from J R Harris & Co.; his information have helped me to conduct a great understanding toward Haiti's building code enforcement.

I would like to thank Professor Nevis Cook and Professor Mettupalayam "Siva" Sivaselvan for their support, contribution, and encouragement throughout my research.

I would also like to thank my friends: Marilyne Lefebrve, Jordan Schemerata, Similoluwa Ogundipe, and all my "roommates" in our researching assistant office, who were always there when I needed help in writing and in the stressed time. Their smiles, hugs, and cares carried me through the difficult time.

I would also like to thank my family for their continued support and love throughout my graduate and undergraduate studies, especially, my Mom, Kim Anh Do, for her advising, critical thinking, and critique.

Above all, I would like to thank my beloved husband, Andrew Geister, who helped me throughout the work. His endless help, love, and engineering enthusiasm will continue to inspire me in the future. I appreciate his help and his support, without him I doubt that I would be confident in my work.

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Chapter 1

Introduction

1.1 The Need for Hazards Risk Management

Environmental risk or disaster events have caused significant exposure to human vulnerability from many forms of natural hazards. Even to a country that is not subjected to natural hazards, there are also risks in daily exposure dangers such as the surrounding environment, political and economic performance, and the health of its society. Engineers are required to manifest their studying by researching and making decisions that affect society. Along with scientists, business leaders and politicians, they bring community development forward. To be able to mitigate risks from natural hazard effects, engineers first need to understand the roots of cause, the possibility of occurrence, and the magnitude of the natural hazards. In addition, mitigation requires identifying which factors determine the vulnerability within the community.

Since the scope of vulnerability itself is complex and contains many aspects, it is essential to know the connection between each component as well as the possible weakness in each component. Because of all the community aspects that are subject to engineering decisions, especially planning actions regarding human vulnerability, understanding risk is essential. To facilitate a concise, valuable, and meaningful approach in mitigating risk, the engineer has to thoroughly comprehend the society, identify the weakest features within the society, and be capable of finding an appropriate resolution to address those features. Accordingly, to a community as a whole, along with social scientists, the engineer has to foresee the area’s highest potential risk, determine the impact of the risk to those areas, and plan the best solution to provide recovery to areas that could be impacted. The tasks of engineers and social scientists associated with the concept of risk management are numerous. Challenge in risk management with respect to natural hazards is that the engineer must act appropriately prior to an event, at the time of a disaster, and after the occurrence. At each point of time in the situation, engineers' acts are needed to perform and adjust in the most precise, effective, and valuable way.

Increase in population and urbanization has led to a rise of human vulnerability exposure. This has led an increase around the world to the costs associated with natural hazards. Reducing human vulnerability requires understanding risk and the ability to measure risk, not only in theory or concept, but also in a quantifiable way. This charge involves engineers providing more than technology or equipment, it also requires the knowledge of risk and the capability to educate the community, as well as construct a preparation plan so that costs from natural hazards can be reduced. Available information surrounding natural hazards and the community are the valuable tools for engineers to develop an approach to deal with risk in all manners of circumstance.

1.2 Motivation and Objectives

The catastrophic damage that resulted from the earthquake in Haiti touched the whole world and led to a great recognition by people about how much damage could have been avoided through the use of risk management. Certainly, if people had been aware of the risk and taken appropriate precautions prior the earthquake in Haiti, the amount of loss would have been much less devastating. More than just providing the technology, aid, and money to help the country, the world expressed a desire to understand a complete picture of Haiti. The author's attitude of frustration toward Haiti's helpless settlement condition brought about the determination of studying Haiti. The subsequent earthquakes in Chile and New Zealand brought a desire to study their situations and extract valuable lessons for Haiti. Together with many researchers who have studied Haiti, , the author hopes this research will contribute to a better understanding of the steps necessary for Haiti to become a more earthquake-resilient society. From an engineering point of view, it is crucial to find such a manifest way to mitigate risk to which Haiti is exposed, so that the impact and the cost from natural hazards will no longer have such a large effect on the country.

Environmental risks are the product of physical pressures in the form of environmental hazards, and human vulnerability (Pellings, 2003). Focusing on the ability to control human vulnerability, this research emphasizes the concept of resilience capacity, one of the components of human vulnerability. Resilience capacity in a society plays an important role in managing risk. Resilience is an ability to overcome the hazard stress and to recover after the stress. Resilience in each country depends upon social, political, and economic history. Because of that reliance, the performance of each country after a natural hazard (an earthquake in this case) will be studied, so that a full picture of the accepted risk level can be viewed. Understanding the whole picture, including the related aspects of resilience which contribute to the development of both a community on a small scale and a country on a larger scale is essential and practical to any societal activist, and especially to an engineer.

1.3 Scope and organization

The level of risk acceptance is different in each of the countries studied. This led to a requirement to study many different factors. Various aspects of vulnerability are identified, especially those that impact the community. History of vulnerability and environmental hazards are reviewed, as well as many social vulnerability adaptations. A framework surrounding consequences of natural hazards is analyzed, including the involvement of exposure, resistance, and resilience, which combine to form vulnerability. This research studies the three countries of Haiti, Chile, and New Zealand over a period of time of more than ten years so that a representation of the trajectory of the society as a whole could be obtained. In addition, the relationship between the social structure and contributed activity is studied. Structure performance and code enforcement prior to and after the occurrence of the natural disaster is described in order to obtain the overall view of which aspects are involved in defining a reconstruction plan.

Chapter 2 includes a summary of the overall picture of Haiti after the earthquake, including damage cost, exposure cities, and structural damages. A study of natural hazards which occurred in the past and the damages caused is also presented. Haiti in this part is presented as an example of a developing country which suffered from many factors including social, political, and economical circumstances. Along with the history of natural hazards this chapter presents comments with respect to the country's preparation toward the historical risk. An overall representation of Haiti will be captured which reflects the pure exposure vulnerability toward risk. A brief definition of risk will be discussed as well.

Chapter 3 describes Chile, which is considered a gap bridging Haiti and New Zealand. Chile was subjected to an earthquake about two months after Haiti. Despite the magnitude of the earthquake being much larger in Chile, the damage in terms of loss of life was much less. The acceptable risk level in Chile under its risk mitigation plan is also discussed. The outline for this chapter is somewhat similar to the previous chapter, although the focus is further specified in building code and enforcement. This chapter reveals the overall country differences between

Haiti and Chile, and also discussed the differences between Chile and the United States in terms of building code and enforcement system.

Chapter 4 provides a distinction of the levels of risk acceptance among the three countries. Similar to Chapter 3, this chapter focuses more on emphasizing the code used within the country, as well as the differences with Chile and the United States. The discussion in this chapter highlights the preparation plan in New Zealand and the achievement of mitigating risk, causing a positive impact such that public safety is enhanced. New Zealand is described as an example of hazard resistance with the use of a new building code application. Updated conditions in New Zealand after it was subjected to the new earthquake in 2011 are listed. In addition, comments on the new earthquake are offered to best present the human vulnerability reduction toward natural hazard risks. Since the damage caused by the two earthquakes in New Zealand mainly was to unreinforced masonry structures and non-structural components, another aspect of discussion is viewed particularly in this subject. It is the consideration of a seismic area in California that is subjected to the rule regarding unreinforced masonry structures. The purpose of viewing the regulatory requirements is so that one can observe the differences corresponding to each individual country and thus quantify which changes might be made for unreinforced masonry structures in Chile and Haiti.

Chapter 5 is a case study about an engineered structure that survived the earthquake in Haiti. Structural behavior during the earthquake is analyzed and will be used for further design in term of retrofitting. The comparison will be based on the two distinct conditions: (1) using the old evaluation approach and (2) using the current available seismic provision code. Overall strengthening recommendations will be made to satisfy the safety requirements for a structure located in a seismic area.

Chapter 6 analyzes available information as well as provides potential measurements which could quantify the risk and the cost from risk. The relationship of economy and level of accepted risk will be presented in graphical display. The ideas behind these relationships will be presented. Damage during an earthquake in particular, or natural hazards in general, will be related to these ideas as well. Resilience in terms of each country's economic development during recovery from the earthquake will be discussed in this chapter.

Chapter 7 summaries the analysis from Chapter 6, gathers all the recommendations for the paper, and concludes the overall remarks of the paper. Environmental risk itself is complex and difficult to understand, and subsequently, being able to offer recommendations to strengthen the framework and the operation of controlling risk is no less problematic. Therefore, the chapter also recommends future research which targets enhancing and filling in the aspects surrounding human vulnerability other than the primary focuses of economic, social, political, and building enforcement features. Overall, the needs for natural hazard risk management will be summarized, and the areas which involve these needs will also be mentioned. Resilience capacity within the society will be drawn as a simple path, there will be assumptions regarding this path, and its future behavior. A conclusion for this paper will remark on the overall picture; it will identify the main factors and solutions for those factors that played such crucial roles in society resilience and human vulnerability.

Chapter 2

Haiti- An example of a developing country

Introduction

On January 12th, 2010 a magnitude Mw 7.0 earthquake hit Haiti, causing major deaths, injuries and property damage. The amount of damage and the current suffering brought international attention. Beyond sympathy, research and analysis of the event and the sources of damage has been and are still currently taking place. To understand the circumstances surrounding the 2010 earthquake and ways to implement a policy to rebuild the country, one must be aware of the history of the event, the natural hazards that happened in the past, demographics, and social, economic and political history of the country itself.

2.1 The Earthquake 2010

2.1.1 History of event

The earthquake that struck Haiti happened at 04:53 PM local time (21:53 Coordinated Universal Time (UTC)). The main shock epicenter was located about 25 km west-southwest of the city of Port-au Prince, 130 km east of Les Cayes, 150 km South of Cap-Haitien in Haiti and 1125 km south-east of Miami, Florida as shown in Figure 2-1. Within two weeks after the primary shock, there were 59 aftershocks with magnitudes 4.5 or greater (USGS, 2010a).

Figure 2-1. Location of Haiti's earthquake epicenter.

2.1.2 Seismological aspects

2.1.2.1 *Geography and tectonic plates*

The Republic of Haiti occupies the western third (27,750 km^2) of the island of Hispaniola, located in the northeast Caribbean between Puerto Rico to the east and Jamaica and Cuba to the west (Fig. 2-2b). Haiti has a total population of approximately 9 million. Its largest city, Port-au-Prince, has an estimated population of between 2.5 and 3 million people within the metropolitan area and is located 25 km ENE of the epicenter as shown in Figure 2-2a on the left.

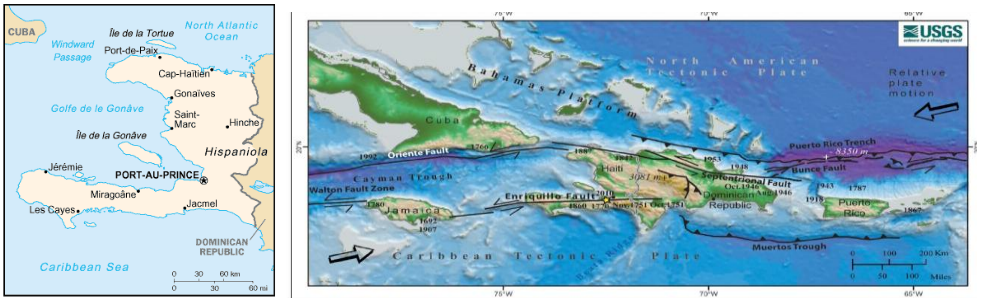


Figure 2-2. a. Map of Haiti (USGS, 2010). Figure b. Geographical setting of the island of Hispaniola (USGS, 2010a).
(Source: http://earthquake.usgs.gov/earthquakes/pager/events/us/2010rja6/index.html)

2.1.2.2 *Seismology*

The earthquake happened in the boundary region which separates the Caribbean plate and the North America plate. Movement was characterized as left-lateral strike slip, and compression between these two plates was about 20 mm per year slip. The Caribbean plate moved eastward with respect to the North America plate (USGS, 2010a). The epicenter of the earthquake occurred at 18.443°N, 72. 571°W, with the estimated hypocenter depth at 13 km below the surface, but this figure is uncertain due to a lack of a seismography station in the region during the main earthquake. The location of the epicenter has a horizontal uncertainty of ± 3.4 km(2.1 miles) (USGS, 2010a).

On September 20th, 2010, it was found by the researcher Brett Israel, the Mw 7.0 earthquake indeed involved not only one, but three faults including the newly discovered Léogâne fault, which contributed 85 percent of the energy released during the January 2010 earthquake. The movement of these three faults warped the ocean floor and caused a tsunami and unusual chain of aftershock events (Israel, 2010).

2.1.3 Strength of earthquake

In the elastic rebound theory in the book *Geotechnical Earthquake Engineering*, Kramer describes about the slow deformation of rock and building up process of strain energy stored. Once the strength of the rock exceeded, rupture happens and strain energy is released. A measurement of work done by an earthquake is called the seismic moment (M_o) and it is given by Equation 1.3-1.

$$M_o = \mu AD \qquad \text{(Eq. 2.1.3-1)}$$

Where: μ is the rupture strength of the material along the fault, A is the rupture area, and D is the average amount of slip.

So M_o is the measure of work done by the earthquake which is correlates well with the energy released during an earthquake (Kramer, page 42).

Moment magnitude (M_w)—a measurement of the strength of an earthquake—is given by Equation 1.3-2. (Kramer, page 42)

$$M_w = \frac{\log M_o}{1.5} - 10.7 \qquad \text{(Eq. 2.1.3-2)}$$

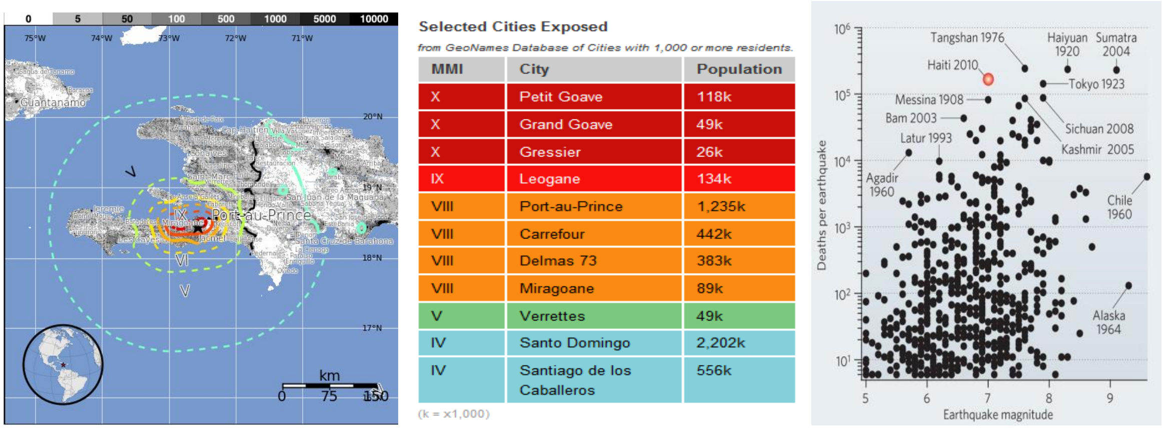
Using Equations 1.3-1 and 1.3-2, the seismic moment of the January 2010 earthquake is:

$$M_o = 3.\ 55 \times 10^{26}\ dyne\ cm \qquad \text{(Eq. 2.1.3-3)}$$

Therefore, the energy released in this earthquake is 3.55 x 10^{26} dyne cm which is equivalent to about half of a million tons of the chemical explosive Trinitrotoluene (TNT) (USGS calculation tool, 2010).

2.1.4 Population at risk and affected

Over nine million people live in Haiti. More than 1.5 million people were directly affected by the earthquake, which was more than 15% of the population of the entire country. The number of recorded casualties exceeded 222,570, and the number of injuries was over 300,000. In addition, at least four people were killed by a local tsunami in the Petit Paradis area near Léogâne. The official death toll plotted in Figure 2-3c showed that the January 2010 earthquake was more than twice as lethal as any previous magnitude-7.0 event occurring in the world (Bilham, 2010). Even ten months after the earthquake, there are still 1.3 million people now living in temporary shelters (United Nations, 2010). The intensity maps and the affected population from the earthquake were captured by USGS 2010, shown in Figure 2-3a, and 2-3b below. As seen in Figure 2-3b, the number of effected population in Port-au-Prince was 1,235,000 people. This number is almost 50 % population of the entire city.



Selected Cities Exposed

from GeoNames Database of Cities with 1,000 or more residents.

MMI	City	Population
X	Petit Goave	118k
X	Grand Goave	49k
X	Gressier	26k
IX	Leogane	134k
VIII	Port-au-Prince	1,235k
VIII	Carrefour	442k
VIII	Delmas 73	383k
VIII	Miragoane	89k
V	Verrettes	49k
IV	Santo Domingo	2,202k
IV	Santiago de los Caballeros	556k

(k = x1,000)

Figure 2-3. a. Earthquake intensity in Haiti.3b. Effected population (USGS, 2010)3c. Haiti's death toll (Roger, 2010)

The earthquake affected segments of the country and its society beyond the area that felt the physical effects of the earthquake. In addition to the massive loss of life in the country, there was also a tremendous loss of knowledge, skill, and other social fabric that will certainly affect the country for years to come. Since earthquake, approximately 150,000 people left the country, and at least 600,000 people abandoned the damaged urban areas to find shelter in the rural areas of the country. This surge in the rural population place a lot of strain to the food supply as well as services provided in these parts of the country (EERI, 2010a). Even if the urban areas are rebuilt, it is not evident that these people would ever return to the city (EERI, 2010a)

2.1.5 Amount of damage

The Haitian government estimates that the damage caused by the earthquake was approximately \$7.8 billion, which is more than 120 percent of Haiti's 2009 gross domestic product (EERI, 2010a and CIA, 2010). This dollar amount was primarily based on the number of dwellings lost in the earthquake: 105,000 homes were completely destroyed and more than 208,000 were damaged. In Port-au-Prince, about 25 km away from the rupture location, the quake caused about 80% of all schools to collapse. Port-au-Prince had also been the center of economic activity. It had the highest number of jobs in the country, and the city generated 85% of the government's revenue. After the earthquake, many jobs were lost, and unemployment increased up to 75 % (EERI, 2010a). The earthquake also destroyed over 80% of the buildings in Léogâne, the city located nearest the epicenter. In the entire country, approximately 1,300 educational institutions and over 50 medical centers and hospitals collapsed or were damaged; and 13 out of 15 key government buildings were severely damaged (EERI, 2010a). The number and severity of damaged buildings and structures were indications of Haiti's deficiencies in the area of building code and enforcement.

2.2 Building and Code Enforcement

Buildings in Haiti can be divided into two categories: those built between 1800 and 1920, and those built from 1920 to the present. The buildings constructed during the time between 1800 and 1920 are categorized as historic buildings. They are: timber frame, unreinforced masonry and reinforced concrete buildings.

2.2.1 Buildings from 1800 to 1920

In general, timber frame buildings performed well under the seismic load (EERI, 2010a). In Bois Verna, a neighborhood of Port-au-Prince, 200 wooden houses known as 'gingerbread' houses withstood the earthquake shown in Figure 2-4a below (Bradley, 2010). Wood buildings in these types of timber frame structures are light and flexible, with diagonal members and interior wooden planks spanning horizontally across the wall framing, providing lateral structural strength. In many cases, however, serious damage was caused due to the deterioration of wood members from termites or rot, thus weakening the members.

Figure 2-4. a. Gingerbread wooden house (Badley, 2010). 4b. Unreinforced masonry building(Hammer, 2010)

Unreinforced masonry failed under the earthquake load, with damage ranging from diagonal cracking in wall sections to collapse (see Figure 2-4b). Failures can be attributed to the lack of brick ties or brick headers between brick wythes, lack of reinforcement, weak stone at critical points, poor quality due to poor aggregate quality, inadequate cement or lime, and poor maintenance.

Reinforced concrete structures adopted European styles. One of these architectural features was the heavy domes found on top of buildings. Rigid first floors and massive concrete dome roofs caused the second floor to act as a soft story. This is the case of failure in both the National Presidential Palace and National Cathedral. (EERI, 2010a)

2.2.2 Buildings from 1900 to present

From 1900 to the present, the early generation Haitian engineers and architects were educated in France, were familiar with the French building design code (AFNOR and Benton Arme aux Etas Limites (BAEL)) which does not include any of the seismic provision. While there were laws in books requiring building permits and inspections, it appeared these were neither followed or enforced (Fouche, 2010).

Structures designed by Hatian engineers as reinforced concrete and reinforced masonry were also built with infill masonry. Infill masonry structures suffered damage at the infill walls and surrounding columns. In these engineered building types, smooth reinforcing bars were used, and widely spaced, particularly in columns (EERI, 2010a). The seismic behavior of infill masonry is still currently under analysis in structural research, but it is understood that this type of structure has no tensile or bending resistance; therefore, overturning and out of plane failure was common and caused the majority of collapses.

The important considerations are that limited engineering knowledge is transferred, there is an absence of building code and record keeping, and there is widespread uncontrolled and unenforced construction practice. Seismic designed application was up to individual initiative and not subject to the consensus or oversight of the government (EERI, 2010a).

The main factors involved in the tragic loss of life during the 2010 Haiti earthquake were that buildings were neither designed nor constructed to resist earthquakes. Observations have shown that those buildings that were designed to resist seismic loads performed well. Additionally, low quality materials and lack of inspections and quality control compounded the severe damage magnitude under the earthquake. Historic patterns of prior earthquakes in the area predict that earthquake with an even larger magnitude could happen any time. This knowledge should be used along with help from the international community when rebuilding Port-au-Prince to develop and enforce proper design and construction practices for Haiti’s structures.

In the next section, Haiti's social, economic and political history is reviewed. Knowing the history of the country can help explain the circumstances the country is in and can provide a basis on developing a policy to be used in rebuilding the country.

2.3Social, economic and political considerations

Haiti is located in the Western Hemisphere and is surrounded by the Caribbean Sea, the Golfe De la Gonave, and the Atlantic Ocean. It covers 10,714 square miles (27,750 square kilometers). The neighboring islands include Cuba, Jamaica, and Puerto Rico. The population of Haiti has grown steadily from 431,140 at its independence in 1804 to an estimated 6.9 to 7.2 million in 2000, making it one of the most densely populated countries in the world. In the 1970s, over 80% of the population resided in rural areas. However today, over 60% continue to live across the rural landscape. The other 30% live in the capital city, Port-au-Prince, which is over five times larger than the next biggest city, Cape Haitian (CIA, 2010).

Haiti is the poorest country in the western hemisphere. GDP of the country as a whole was 11.99 billion US dollars and 1,300 US dollars per capita in 2009 (CIA, 2010). Over the past five years, the economy of Haiti grew slowly with the small annual percentage of 2.3% from 2004 to 2009 after a decline of 0.7% from 2000 to 2004 as shown in Figure 2-5 (US Department of State, 2010). Despite of this small recent improvement, the occurrence of the 2010 earthquake put Haiti in a positon of ecomomy crisis. This economic situation combined with natural hazards in the form of earthquakes and hurricanes places Haiti in a unique and difficult position. Both economic problems and natural hazards have amplified the exposure of Haiti to risk. A concern is the degree to which this level of poverty and lack of social and economical resources increases the amount of risk the government is willing to place on its citizens. An unanswered question is whether the devastation that the citizens of the country experienced changes the acceptability of this risk to human life.

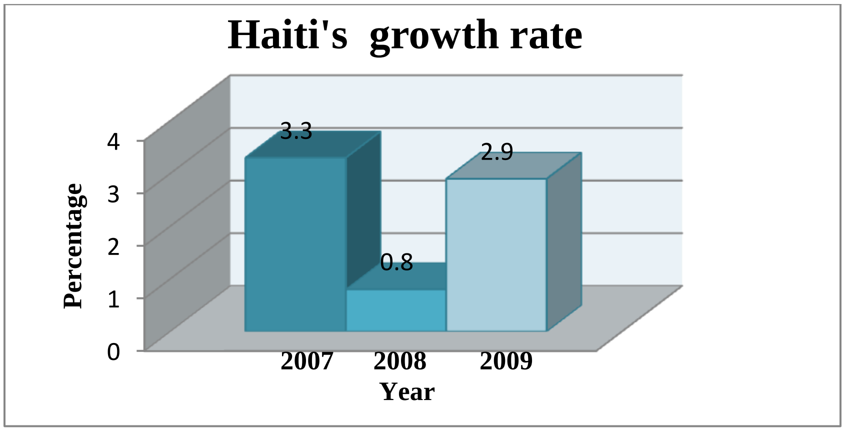


Figure 2-5. Haiti growth rate from 2007 to 2009

Another factor that has challenged Haiti has been its political environment. Ever since the country won its independence from France in 1804, Haiti has been plagued with economic instability and political corruption. There have been 55 leaders of Haiti since the country won its independence, but only nine of them were able to complete their presidential terms. The remaining leaders died during their terms, were killed, or were forced out of office (Buss, 2008). Many of these leaders were reported to have taken advantage of their citizens and the island's natural resources for personal and political gain. Citizens were often aware of this, and as a result, there were few times in the country's history when there was peace and stability (Buss, 2008).

Another concern is that earthquakes are not the only natural hazards to strike Haiti. In the past, Haiti has suffered hurricanes and tropical storms, briefly covered in the next section. This history is important because as the country regularly experiences these disasters, but no building codes are established and enforced to protect the people, one asks what the Haitian government's priorities truly are. Perhaps these decisions are the result of the government's limited knowledge of seismic structural design or its willingness to assume a high level of risk due to competing economic factors for limited resources. An important question is whether some of the financial aid promised Haiti should be required to be used for seismic code development and enforcement for the reconstruction of Port-au-Prince and its environs.

2.4History of Earthquakes and Other Natural Nazards

2.4.1 Earthquake history

Since 1964, the southern Port-au-Prince region of Haiti only experienced one earthquake with magnitude greater than 4.0, with several additional events occurring 100 km to the west (USGS, 2010a). Large earthquakes happened in Haiti in 1701, 1751, 1770, and 1860. The 1770 earthquake resulted in the widespread destruction of buildings in Port-au-prince and Léogâne and was estimated to be about 30-50 km to the west of the Enriquillo fault, which was first believed to be the same fault that produced the 2010 earthquake. The 1860 earthquake was located farther west of Port au Prince, and also was observed to cause uplift of the sea floor. Thus this particular area of Haiti has experienced a well documented history of large earthquakes (USGS, 2011a).

2.4.2 Tropical storms and hurricane

Within the past fifteen years, Haiti underwent tropical storms, hurricanes, and other types of natural hazards. Table 2-1 below lists the loss of life that Haiti endured and the environmental damage after the natural hazards.

Year	**Hurricane**	**Death toll**	**Environmental damage**
1994	Hurricane Gordon	More than 1000 deaths	Washed off 96% of forest
1998	Hurricane Georges	More than 400 deaths	Destroyed 80% of crop
2004	Hurricane Jeanne	More than 3000 deaths	Destroyed 70% of urban infrastructure (crop, houses, etc) on the West side of Port-au-Prince.
2008	Hurricane Fay, Gustay, Hanna and Ike	More than 793 deaths	Destroyed 70% crop

Table 2-1. Natural hazards in Haiti from 2004 to 2008
Source:http://www.reliefweb.int/rw/rwb.nsf/db900SID/AMMF-82SVYU?OpenDocument&rc=2&emid=TC-2004-000098

Clearly, the impact of natural hazards on Haiti's economy is considerable. Haiti constantly deals with the results of these influences. How can a country recover when it must defend itself from seemingly nonstop disasters? Such events constantly remind us that Haiti is not immune to the force of nature, which is directly associated with risk to the country's communities. In addition, these events showed that the threat to health and livelihood from natural disasters continued adding to Haiti's exposure in a dynamic way. The damage from these natural hazards caused the decaying conditions of soil, forests, and land usage. But how deep do these causes of risk go and to what extent are shared patterns of risk generation amenable to common policy response? This is a critical question for Haiti's government or authorities. Some dialogue and possible answers to this question are offered in the following discussions.

As seen in the previous sections of this paper, when disasters struck the country, the effects were catastrophic. But what factors actually determine the vulnerability of the country and its people? To answer this question, one must be aware of risk and the literature on disasters as well as their impacts on society.

2.5 Risk- Risk Management

Because disaster studies often involve multiple disciplines, words often have compound implications. Table 2-2 provides definitions for some key terms (Pelling, 2003)

Key Terminology	
Risk	To be threaten by harm. To be at risk is to be under threat of harm.
Hazard	The potential to harm individual or human systems. In this work, hazard is ascribed to natural, physical or environmental elements. It can be everyday (scarcity of clean drinking water or episodic).
Vulnerability	Denotes exposure to risk and an inability to avoid or absorb potential harm.
Physical Vulnerability	Vulnerability in built environment.
Social Vulnerability	Vulnerability experienced by people and their social, economic and political systems.
Human Vulnerability	The combination of physical and social vulnerability
Resilience	The capacity to adjust to threats and mitigate or avoid harm. Resilience can be found in hazard-resistant building or adaptive social systems.
Disaster	The outcome of hazard and vulnerability coinciding. Disaster is a state of disruption to systemic functions. System operates at variety of scales, from individuals' biological and psychological constitutions or local socio-economies to urban infrastructure networks and the global political economy.

Table 2-2. Key terminology (Mark Pelling, 2003).

2.5.1 The earthquake 2010 and its reminder of risk

The January 2010 earthquake reminded both the world and Haiti about the existence of risk and Haiti’s predispositions to risk. This earthquake shows that the exposure to risk has gotten worse for a country faced with many disasters throughout its history. Risk has always existed, but, as evident in this earthquake, the Haitians lack understanding of what these potential risks are. This ignorance could be a result of the country being under-developed. Haitians need to understand that the risk they have faced in the past—combined with their ignorance—placed a burden to both their own development and the resources of the countries trying to aid them in their recovery.

2.5.2 Haiti's Disasters

2.5.2.1 Natural disaster

Earthquakes, tsunamis, hurricanes, tropical storms, droughts, and landslides are all natural hazards to which Haiti is vulnerable. Haiti's geology and the natural and built characteristics of its surrounding environment largely produced the exposure to risk. Inadequate preparation for natural disasters has a direct effect on the income and economy of a country, and has an even bigger impact if loss of life occurs. Planning in advance for these natural hazards is a feasible way to help people, reduce the loss of life and the expense of recuperation and reconstruction. Planning for natural disasters is a need for Haiti as significant as response to the natural disasters. Unfortunately, what to do and how to prepare natural hazards are never covered in primary and secondary schools, and the opportunities for adults to receive information and training on the subject are rare (NATHAT, 2010). There may be an opportunity to change this manner toward risk so that Haitians can be educated and equipped with the attitude of facing natural hazards.

2.5.2.2 Human Vulnerability

It is always essential to understand nature of hazards, but the influence of social component is as important as the natural hazard itself. Creation of a dense population, a lack of adequate building standards, a lack of the enforcement of the code, the catastrophic state of environment, disorganized land use, and an unbalanced division of economic activity are all factors that increase social and physical susceptibilities to disasters. These social factors can get worse with time if there is no improvement. The relationship between these social factors and the risk exposure are proportional—the devastation a community could encounter after a disaster increase if these social and physical vulnerabilities are not properly identified and dealt with.

2.5.2.3 Disaster

It is important to note that a community's susceptibilities to a disaster are the result of both nature and human activity (Pelling, 2003). The distinguishing characteristic of risk is that climatic and seismic hazards cannot be prevented. Fortunately, human vulnerabilities—factors that the people themselves cause—can be minimized (Lou Zoback et al., 2010). Haiti has many of these vulnerabilities that need to be addressed, and help is needed to solve the problems brought forth by these factors. The question is how can we address these vulnerabilities, and what specific parts should resources be concentrated toward? Most of the components in human vulnerability can be organized into three categories: land reform or population density organization with economic growth and job creation, development a standard code for structures along with enforcement, and preparation for the response to natural hazard. All three of these factors require extensive combined involvement and coordination of politics, social sciences, and engineering in order for Haiti to be more resilient to disasters.

2.5.3 Response to natural hazard

Identifying the threats from natural disasters is complicated, and distinguishing between threats to life and livelihood from natural disasters and other sources is even harder. Awareness of natural hazards and a plan of response is as significant as reducing the human vulnerability itself.

The struggle of daily survival for the people of Haiti is heavily-pronounced in this impoverished country. These struggles divert attention away from getting an organized plan of disaster mitigation put in place. Because of this diversion, the people needlessly suffer after a disaster: they are poor to begin with, and after a disaster, they become poorer and more helpless.

It is true that the magnitude of a natural hazard is often hard to predict, although its average frequency is possible to obtain. If the awareness of natural hazards can be achieved, then subsequently, the human component to the exposure of risk can be reduced and the capacity of a community's resistance to risk can also be enhanced. Activities that Haiti could possibly pursue include:

- Offer special training at a special time schedule.
- Prepare the service reserves to respond when an emergency happens.
- Improve weather reports to include disaster preparedness.
- Enhance the human resources of community activists and leaders.
- Increase group leaders' awareness, skills, and external resources in order to increase the effectiveness of their roles.
- Improve communication from government leaders to local communities.

2.6Summary

Of all the challenges faced by the Haitian people, risk management is the most complex. There are small signs of recovery in Haiti as evident from the day to day moving of debris, organization of shelters, and business slowly reopening (Economist, 2011). Yet, Haiti's revival still needs time and extra help from countries around the world. Since natural hazards will always exist as a threat to the country, Haiti needs a plan to rebuild, reorganize, and prepare their country. Rehabilitation of Haiti's people and repairing the country's critical infrastructure is their first priority. Once the people are adequately secured, the country can then concentrate their resources in disaster mitigation. For this to occur, the Haitians are required to combine their effort to help revitalize their country for their own sake.

Chapter 3

Chile- an example of developed country

In order for Haiti to move forward after this disaster, they must learn a few lessons from other countries that have previously dealt with similar disasters. It is vital for them to know not only the similarities of risks these countries share, but also the differences in how these countries react to them. In general, if potential problems are known and planned for in a community, then the negative consequences brought forth by these risks are reduced. Of course, after a disaster, damages and loss of life are expected; however, they would be minimized if the community is properly aware of these risks and enacts plans to deal with them. Two countries—Chile and New Zealand—will be examined in subsequent parts of this paper.

Even though Chile and New Zealand are developed countries, they share the same risks of seismic vulnerability with Haiti. However, these two developed countries react to the risks very differently from Haiti, and disaster mitigation and preparedness actions are taken seriously in these two countries. Each country will be investigated and conclusions made on how Haiti can implement a similar program on disaster mitigation. First, Chile's experience is represented here as a case study of a kind of community that is resilient to environmental hazard. The following section will center on disaster mitigation in Chile. Key differences between Haiti and Chile will be highlighted, and conclusions will be drawn on what lessons Haiti can take from Chile.

Introduction

Despite the large magnitude of the earthquake, the number of deaths, injuries, and buildings damaged were considerably less than Haiti—a country that experienced a smaller earthquake but has no seismic code (Bailey, 2010). Chile's actual damage amount in dollars was estimated to be higher than in Haiti because of the existence of more modern buildings and infrastructure. Chile is considered as a First World country, which means it is a developed and economically advanced country. The government of Chile recognizes the seismic threat and enforces a strict building code called the NCH 433 (1996) (Harris, 2010). This code was designed based on the survival of buildings after an Mw 8.0 earthquake devastated Santiago in March 1985 (Mohlle, 2010).

The intent of seismic building codes is to prevent damage in small and moderate earthquakes, but to tolerate some damages in large earthquakes such as the one that struck Santiago last February: the intent, after all, is to protect human life by preventing collapse of the infrastructure (EERI, 2010b). The 2010 earthquake had a moment magnitude of 8.8, which was larger than the design earthquake considered in the code. Therefore, it is not surprising that the damages occurred. Because of the economic status of the country, one would expect that Chile has the ability to reduce future earthquake losses in terms of both lives and economics by further updating and improving its seismic building code. Beside the view of social and political history, other goals of this section are to summarize the damage of concrete and masonry buildings, damage to the nonstructural elements such as pipes and mechanical equipment, and to briefly identify the differences between Chile's code and that of the United States at the time of adoption (1996).

3.1 The earthquake 2010

3.1.1 History of event

On February 27, 2010, an earthquake with magnitude Mw 8.8 hit the central region of Chile. The main tremor occurred off the coast of the country at 3:34 am local time (6:34 UTC). Following the primary shock, over 300 aftershocks occurred with magnitudes of 5.0 or greater over the period of two months. In fact, twenty-one of these were at magnitudes 6.0 or greater (USGS, 2010). The epicenter of the 2010 earthquake was 105 km (65 miles) north-northwest of Conceptión off the coast of the country shown in Figure 3-1. As the main earthquake occurred, the ocean floor warped and caused a destructive tsunami (Universidad de Chile, 2010). The earthquake moved the city of Concepción three meters (ten feet) to the west of its previous location, and moved the capital, Santiago, about 28 centimeters (11 inches) to the west-southwest (AON Benfield, 2010).

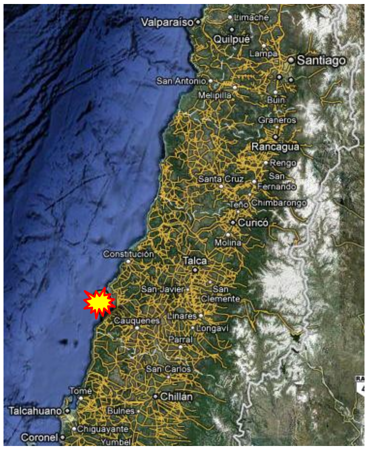


Figure 3-1. Location of the epicenter in Chile earthquake.

3.1.2 Seismological aspects

3.1.2.1 *Geography and tectonic plates*

The types of earthquakes to which Chile is susceptible are those that typically occur at the subduction zones, as seen in Figure 3-2. The subduction zones are known to produce the most powerful earthquakes on earth since the geological make-up of the subduction zone allows more stress to build up before the energy is released in the form of an earthquake (Hayes, 2009).

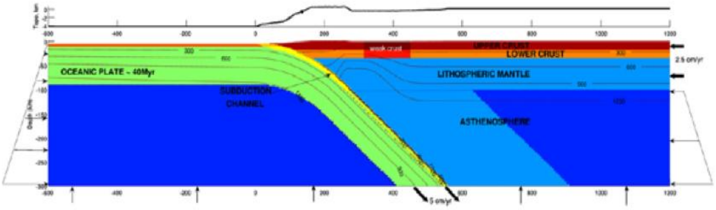


Figure 3-2. Cross- section of the subduction zone (Gerbault et al., 2009)

Shown in Figure 3-3, the earthquake occurs at the boundary of two plates: the Narza Plate and the South American Plate, with the Narza plate moving eastward and sliding beneath the South American plate. This 2010 earthquake was actually produced by the same fault and 230 km north from the epicenter of the historic 1960 earthquake (EERI, 2010b)

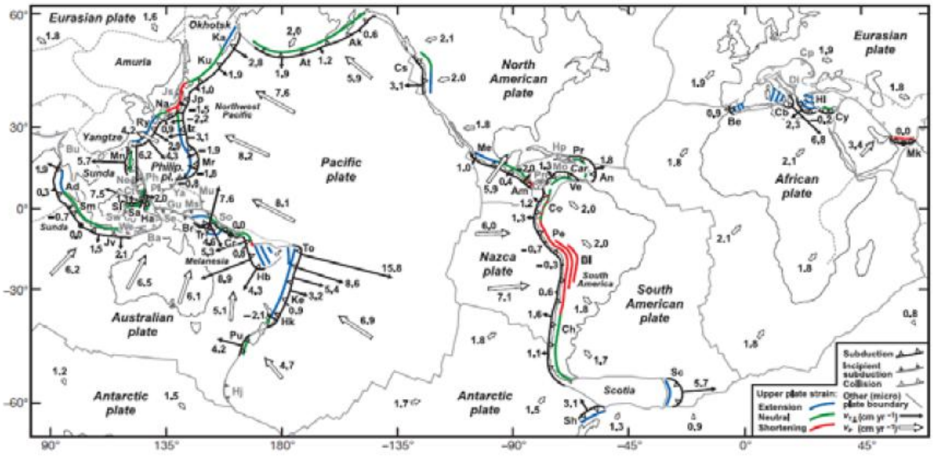
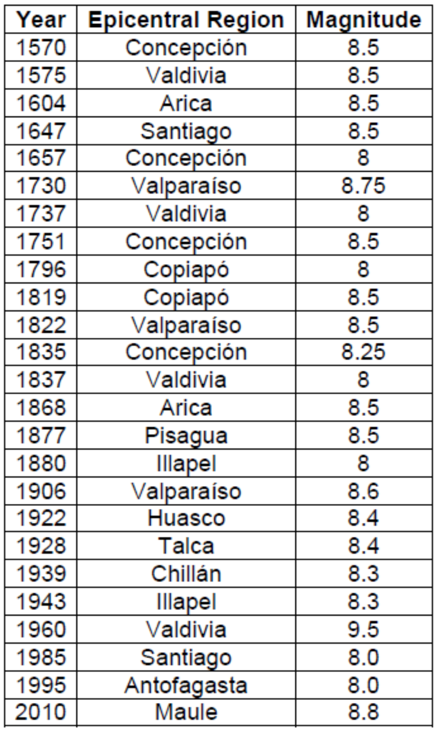


Figure 3-3. Subduction zone between the Nazca and South American plates (Schellart et al., 2007)

3.1.3 Seismology

Chile is one of the most seismically active regions in the world. A major earthquake with magnitude greater than 8.0 happens every fifteen year on average (USGS, 2010). The largest earthquake ever recorded by seismic instrument with magnitude of Mw 9.5 occurred on May 12, 1960, as shown in Table 3-1.

On March 3, 1985, an earthquake with a moment magnitude of 8.0 struck the same region, causing millions of dollars of damage to buildings and infrastructure in Santiago, although only 177 people died in that earthquake (USGS, 1985). The largest earthquake ever recorded in the world happened in Chile on May 22, 1960 with moment magnitude of 9.5 and killed approximately 2000 people in Southern Chile, Hawaii, Japan, and the Philippines (H. Carrol Talley, 1960). In the 20th century, over 75 earthquakes of magnitude 7.0 and higher struck Chile (Universidad de Chile, 2010)



Year	Epicentral Region	Magnitude
1570	Concepción	8.5
1575	Valdivia	8.5
1604	Arica	8.5
1647	Santiago	8.5
1657	Concepción	8
1730	Valparaíso	8.75
1737	Valdivia	8
1751	Concepción	8.5
1796	Copiapó	8
1819	Copiapó	8.5
1822	Valparaíso	8.5
1835	Concepción	8.25
1837	Valdivia	8
1868	Arica	8.5
1877	Pisagua	8.5
1880	Illapel	8
1906	Valparaíso	8.6
1922	Huasco	8.4
1928	Talca	8.4
1939	Chillán	8.3
1943	Illapel	8.3
1960	Valdivia	9.5
1985	Santiago	8.0
1995	Antofagasta	8.0
2010	Maule	8.8

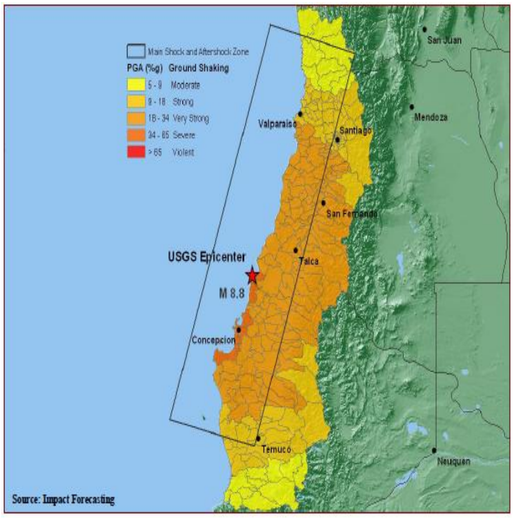
Table 3-1. Chile's earthquakes from the past (USGS, 2010)

3.1.4 Strength of earthquake

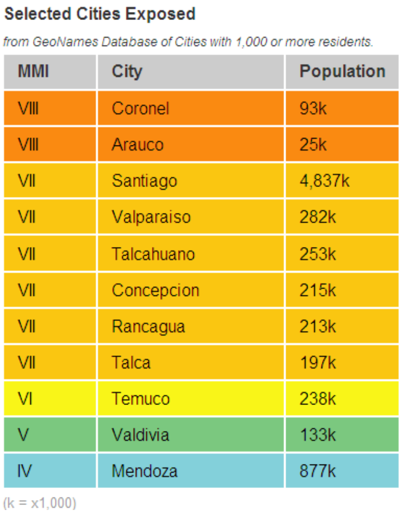
Using the same relationship as mentioned in Chapter 2, section 1.3, for $M_w = 8.8$, one can calculate the work done by the earthquake is M_0 =1.77*10^{29} dyne-cm, which is equivalent to about 250 million tons of the chemical explosive Trinitrotoluene (TNT).

3.1.5 Population at risk and affected

The population density in Chile is much greater than in Haiti, and more than eight million people live in the area affected by the earthquake in Chile. According to the Chile National Institute of Statistics, more than two million people live in the six regions directly affected by the earthquake: Tamuco, Concepcion, Talca, San Fernando, Valparaiso, and Santiago, as shown in Figure 3-4 (AON BenField, 2010). The damage estimation is much higher in Chile than in Haiti: 30 billion US dollars. In contrast to Haiti, only 521 people in Chile died and 12,000 were injured from the earthquake and the resulting tsunami (USGS, 2010).



Source: Impact Forecasting


Selected Cities Exposed

from GeoNames Database of Cities with 1,000 or more residents.

MMI	City	Population
VIII	Coronel	93k
VIII	Arauco	25k
VII	Santiago	4,837k
VII	Valparaiso	282k
VII	Talcahuano	253k
VII	Concepcion	215k
VII	Rancagua	213k
VII	Talca	197k
VI	Temuco	238k
V	Valdivia	133k
IV	Mendoza	877k

(k = x1,000)

Figure 3-4. Population affected (USGS, 2010).

3.1.6 Damage experienced

There was also significant damage to buildings and infrastructure due to the Chile earthquake. It damaged 370,000 houses, 4013 schools, and 79 hospitals (EERI, 2010b). Among the damaged buildings, there were 54 constructed of reinforced concrete, of which four suffered total or partial collapse (EERI, 2010b). Overall, there was a lot less disruption after the Chile earthquake, even though it was much more powerful than the Haiti earthquake.

Not only were the buildings damaged by the earthquake, but there was also localized liquefaction that caused significant damage to buildings. An example of building damage due to liquefaction and ground deformation is the hospital in Curanilahue. The individual structural wings (ranging in height from 1 to 6 stories) experienced settlement and rotation due to liquefaction (EERI, 2010b). The Rieso building experienced 30 cm settlement. Some homes in the northern region of Concepción were torn completely apart by the lateral ground movement (EERI, 2010b).

3.2 Social, economic and political considerations

Chile shared one thing with Haiti with regard to their political histories: both countries experienced political instability that negatively affected their citizens. In the case of Chile, their government first metamorphosed from a Parliamentary Republic into a Presidential Republic in the early part of the 20th century. At the turn of the 20th century, Chile's parliament was controlled by a ruling oligarchy which exerted power over the democratically-elected president. For instance, the president was required to appoint his cabinet members based on who was the ruling party in parliament. The oligarchy began to lose their influence over the country in the 1920's. There was a time where there was great political instability, for in the years 1924 to 1931 a military coup ruled the country. After 1931, the powers of the government shifted from the parliament to the president. At first, Chile was able to resist both fascism and socialism. However, as time progressed, Chillan politics began to be more polarized. For the next forty years, presidents either pushed the country to the left or to the right. Thanks to an ever-polarizing political party system, the government itself became gridlocked as there were many disputes between the members of parliament and the president. The breaking point came in the 1970's, when the president attempted to energize the economy while redistributing wealth to the poorer classes at the same time. Because the right and the left had such different visions of their country, compromise was impossible (Garretón, 2001 and Puryear, 1994). Hence, in 1973 the military took over the government.

For the remainder of the 1970's, the military-controlled government detained, tortured, and killed thousands of people. The military got rid of individual freedoms and dissolved parliament. Because of the oppression, thousands of Chileans fled the country. Unlike Haiti, however, there was a unified opposition to the government (Garretón 1989). It seems as though people had never forgotten that at one point they were a republic. The government took notice to this idea, and began to loosen its hard grip on the country.

Starting in the 1980's, the government gradually transformed back into a democracy. People again had the right to freely express themselves and to elect their leaders. The military improved their educational system so that their own citizens rather than the foreigners can contribute to the economy (Puryear, 1994). The military also reversed many of the social reforms that were done earlier in the decade as an attempt to stabilize the Chilean economy (Garretón, 2001). As a result, the middle class was able to grow again, and poverty decreased. Today Chile is a successful republic. Their people are able to freely participate in political discourse while at the same time enjoying a high standard of living. Haiti has a lot to learn from

Chile when it comes to improving their society so that everyone-from the working class to the elite-can benefit.

Despite this period of political instability, Chile was able to move forward economically and socially, making sure that their citizens were treated fairly. For instance, in the early 1970's, the Chilean economy was struck by a depression, inflation, and workers' strikes. In 1973, the Chilean government was overthrown by a military coup that later would be known for committing human rights violations, torture, and even murders. In the 1980's, Chile had recovered economically, and the government gradually began to grant its people more freedom (Schneider, 2007). Chile's GDP in 2009 was 242.2 billion US dollars and 14,600 per capita. The GDP of Chile increased with an annual average near 4 percent since 1999 (CIA, 2010). The damage from 2010 earthquake impacted about 11% of Chile 2009 gross domestic product. This number will be discussed in more detail later in this paper. In contrast with Haiti, Chile has a reputation of being the strongest and most stable economy in South America. During the early 1990s, Chile's reputation made it an international role model for economic stability and growth. It was also during this time period that Chile's seismic design code was adopted, indicating that Chile's strong economic status helped give it the opportunity to develop and improve other aspects of its society. In 1996, NCh433 was adopted and included a similar analysis procedure to that appearing in the 1997 UBC. As a result, when strong earthquakes struck the country the buildings were overall well-designed and up to code so there was a minimal loss of life.

3.3 Buildings and Code Considerations

3.3.1 Buildings:

There is a variation of building types found in Chile: reinforced concrete, timber-frames, confined masonry, reinforced, and unreinforced masonry. Generally, confined masonry structures performed well during an earthquake. For clarification purposes, confined masonry is built by constructing the masonry panel first, and then a concrete frame is cast around the masonry. As the concrete cures and shrinks slightly, the masonry is compressed, behaving like a post-tensioned structure. Poorly reinforced masonry and timber frame homes generally performed poorly under the seismic loading. In contrast, reinforced concrete and confined masonry structures generally performed well. Typical damage to these structures included diagonal cracking or wall failure due to lack of boundary elements or vertical displacement in buildings with stacked openings (Leon, 2010). Unreinforced masonry structures experienced the most catastrophic failure: collapse of portions of the building. This type of construction includes churches, older structures, walls in homes, and fences (Tanner, 2010).

Not only is the structure of buildings vulnerable to the effects of an earthquake, but the building's nonstructural components are also prone to damage. This type of damage greatly affects hospitals, airports, utilities, and services. Even though the building's structure may not be damaged by an earthquake, the nonstructural components such as suspended ceilings, mechanical and electrical equipment, and plumbing might be so significantly damaged that the building is left inoperable. In some cases flooding or water damage occurred when pipes burst underground or in buildings. Many buildings, even if they suffered no damage, experienced loss of power, water, or communications services that hindered the recovery of the community after the earthquake (Miranda, 2010).

3.3.2 Code's enforcement

Unlike Haiti, Chile has a nationalized building code and it is enforced rigorously by the government. The seismic structural code of Chile, NCh433 (1996), has many provisions based on ACI 318-95and ASCE7-05. It does not, however, limit vertical irregularities in calculating the seismic response coefficient *C* (Moehle, 2010), as compared to the limitation of seismic shear force calculation that referenced ASCE7-05. Nor does NCh433 require the provisions of ACI that address boundary elements in walls. Because of this, what was found in many walls that failed were concentrations of vertical bars at both ends, and widely spaced bars in the middle, as shown in Figure 3-5 below (Leon, 2010). With tensile strength of the wall concentrated at the ends, the steel could not reach yield, and brittle crushing of concrete occurred as seen in the following picture. In contrast, ACI requires hooks or U-stirrups to resist buckling of vertical edge reinforcement (ACI 318, 1995).

Figure 3-5. Damage due to concentration of vertical steel bars at end of walls (Leon, 2010)

NCh433 1996 Section 8 for secondary elements enforces the anchorage and tying of non structural components. According to EERI's newsletter report (EERI, 2010b), the enforcement of this provision in Chile actually depended on the building owner. One of the most noticeable examples after the earthquake is the closure of the international airports in Santiago and Conceptión, which are major air transportations in Chile (Miranda, 2010). About 60% of the 130 hospitals were temporarily taken out of commission by nonstructural failures, which caused a substantial dollar loss to the economy and put patients' lives at risk (Meade et al., 2010)

There is certainly no building that can be designed to be completely earthquake-proof. The cost of constructing such a structure would be too expensive. The earthquake that happened in Chile in February 2010 showed that Chile's design code and enforcement were able to protect many lives and minimize structural damage. Although many buildings were damaged beyond repair, lives were saved by preventing total collapse. The results of this earthquake served both as a lesson and as a reminder for Chile in its approach to seismic codes. The building code they enacted and enforced saved many people's lives because buildings do not collapse. However, the consequences of damage to nonstructural elements were also demonstrated, and in some buildings this was the only form of damage (Miranda, 2010). The lesson for Chile is that even though they have a building code in place, the code itself needs to be updated because of unforeseen damage seen in the earthquake—in this case, to the nonstructural components of the building.

3.4Summary:

So far, the paper discusses the differences between the earthquake effects in Haiti and Chile. Powerful earthquakes occur more frequently in Chile than in Haiti. Because Chile is a developed, stable country, it was able to enforce a modern, strict building code. Although the dollar amount of damage in Chile was large, the code minimized the loss of lives, and the economic loss was a much smaller fraction of the GDP of the country. The difference in the construction methods and the building types in Haiti and Chile had a tremendous impact in the aftermath of the earthquakes. Because there is a standardized building code in Chile, fewer people died than in Haiti. The irony of the building code, however, is that the repair costs of a modern building are much higher than in a building typically found throughout the developing world. Because of what happened to Haiti in January, it is critical to have a building code in place because human lives cannot be replaced. One challenge facing Haiti if it were to enact a seismic building code, however, is the affordability in relation to the tradeoffs of other needs of society.

Chapter 4

New Zealand-An application of a modern building code

Chile's experience has been presented as an example of connecting the gap between Haiti—a community whose ability to reduce disaster vulnerability or loss is limited—and New Zealand—a country that has sufficient resources and stability to develop and implement procedures to resist disaster vulnerability. New Zealand's experience is presented here as an example of natural hazard resistance with an application of modern building code. In this section, the topics to cover include factors such as New Zealand's application and monitoring of building codes, organizational capacity of the local governments, and response of the country during catastrophic disaster. The purpose of studying New Zealand is to help determine what should be the long term decisions in addressing the development of hazard mitigation directive in Haiti in the future.

Introduction

Six months later in the same year as the Haiti and Chile earthquakes, a major earthquake struck Christchurch, New Zealand. Despite the magnitude of the quake being larger than those experienced by both Haiti and Chile, the damages were considerably less than from the events in both those countries. What factors helped New Zealand be better prepared to resist earthquake damage? As mentioned in the previous two parts, social and political history played important roles in community vulnerability; do they also play similar roles in New Zealand? If not, what will be the main factor which can help resistance capacity and resilience capacity of a society?

These questions will be answered as a point of studying a developed country with hope to emphasize lessons for both Haiti and Chile to learn.

4.1 The Earthquake 2010

4.1.1 History of event

At 16:35:45UTC (4:36 am September 4 local time) on September 3, 2010 an earthquake with magnitude of Mw= 7.1 struck South Island, New Zealand. The rupture was a result of strike-slip faulting within the crust of the Pacific Plate, near the eastern foothill of the Southern Alps at the western edge of the Canterbury Plains (USGS, 2010d). The epicenter was around 37 kilometers west of Christchurch, near the town of Darfield. Because of this, its scientific name is the Darfield earthquake, though it is more widely known as the Canterbury earthquake. It was relatively shallow earthquake – about 10 kilometers below the surface of the Canterbury Plains – and produced the strongest shaking ever recorded in New Zealand. Ground near the epicenter experienced horizontal acceleration up to 1.25 times the acceleration due to gravity. The earthquake was accompanied by a large surface rupture.

It is important to note that there were nineteen earthquakes of a magnitude of 5.8 or higher that struck the country in the 20th century and in the first part of the decade. The deadliest of these earthquakes happened on February 3, 1931. On that day, there were 256 casualties and thousands of injuries when a magnitude 7.8 earthquake struck the Hawke's Bay region of New Zealand. Although the earthquake that struck New Zealand in September 2010 was the most damaging earthquake that hit the country since the earthquake in 1931, there were no deaths (GeoNet, 2010).

4.1.2 Seismology aspects

4.1.2.1 Geography and tectonic plates

New Zealand is located about 1,250 mi (2,012 km) southeast of Australia, comprised of two main islands and numerous smaller scattered islands. The islands are so widely spread that their weather ranges from the tropical to the Antarctic. New Zealand's two main components are the North Island and the South Island, separated by Cook Strait. The North Island contains 44,281 sq mi (115,777 sq km) and South Island contains 58,093 sq mi (151,215 sq km). Christchurch is the largest city in South Island, and the principal city of the Canterbury region. It has a population of 376,700 as of June 2010 (CIA, 2010). Christchurch city itself is generally flat. It lies on the coastal periphery of a wide alluvial plain (Christchurch City, 2010).

Figure 4-1.a. Fault zone in New Zealand. 1b. Greendale fault 1c. Road offset due to fault (Jongens et al., and Begg, 2010)

The earthquake that struck this part of New Zealand was classified as a result of a strike-slip fault. This type of fault is a strike-slip focal mechanism with a right lateral focal plane striking east-west. A fault rupture occurred along a previously unknown fault line, which has been named the Greendale Fault. Greendale Fault is a fault that has not ruptured in the last 16,000 years. Movement along the fault broke the surface, creating a fault trace that extends for

30 kilometers west from Rolleston, one of Christchurch's provinces. As seen in Figure 4-1b and 4-1c above, roads, fences, shelter belts and irrigation channels were offset sideways, in places up to 5 meters, with up to 1.3 meters vertical offset. The area to the north of the fault rupture moved eastward and the area to the south moved westward (GNS Science, 2010).

Within two weeks after the earthquake, there were more than 550 aftershocks with magnitude Mw greater than 3 (EERI, 2010c). Some aftershocks were strong enough to cause damage to already-weakened structures. The aftershocks were mainly clustered along the Greendale Fault. As some of the aftershocks at the eastern end of the Greendale Fault were close to Christchurch, they were felt particularly strongly.

4.1.3 Seismicity

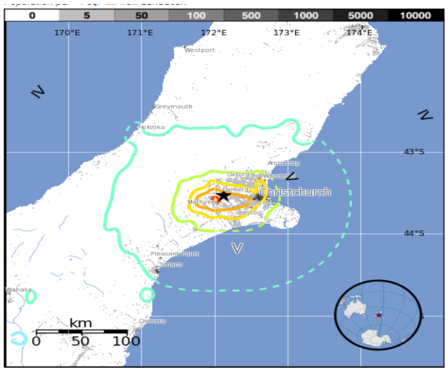
New Zealand straddles the boundary of the Australian and Pacific plates. Relative plate motion of these two plates is obliquely convergent across the plate boundary at about 50 mm/yr in the north of the country, 40 mm/yr in the center, and 30 mm/yr in the south (DeMets et al., 1994). The complex faulting associated with the changing orientation of the subduction zones in the Northeast and Southwest (Figure 4-1a). The fault changes from subduction zone at the edge of the Hikurangi plate to strike- slip orientation within the central volcanic region and Marlborough fault zone (Figure 4-1a). As a result of this combination, New Zealand is a region of distributed seismicity. The relative movements of the Australian and Pacific plates are not accommodated by one or two faults in a narrow zone, but in many faults across a wide zone. That is the reason New Zealand has suffered from many large earthquakes, occurring in almost every region of the country (GNS Science, 2010).

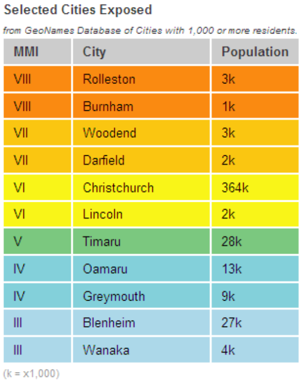
4.1.4 Strength of earthquake

Using Kramer's equation again for the moment magnitude of 7.1, the strength of the earthquake was computed and equaled to 4.66 x 10^{26} dyne cm, which is equivalent to about two third of a million tons of the chemical explosive Trinitrotoluene (TNT) (USGS calculation tool, 2010).

4.1.5 Population affected

New Zealand's population as of July, 2010 was 4,252,277 (CIA, 2010). The population of Christchurch, the directly affected area by the earthquake itself, was 364,000. There were only two people seriously injured by the earthquake (USGS, 2010d). The percentage of affected population injured from the earthquake is considerably smaller than in Haiti and Chile. The New Zealand earthquake happened at ground surface, therefore there was no effect of tsunami. However, the damage from liquefaction was severe and will be covered in the next section. From selected exposed cities in Figure 4-2b below, the affected population in Christchurch itself was up to 95% of the population in the three areas experiencing the largest Modified Mercalli intensity.





Selected Cities Exposed

from GeoNames Database of Cities with 1,000 or more residents.

MMI	City	Population
VIII	Rolleston	3k
VIII	Burnham	1k
VII	Woodend	3k
VII	Darfield	2k
VI	Christchurch	364k
VI	Lincoln	2k
V	Timaru	28k
IV	Oamaru	13k
IV	Greymouth	9k
III	Blenheim	27k
III	Wanaka	4k

(k = x1,000)

Figure 4-2.a. Intensity map. **2b. Population affected (USGS, 2010).**

4.1.6 Damage estimation

Estimated damaged during the earthquake was 3 billion US dollars (Withers et al., 2010). To stay consistent to what has been done throughout the paper; it is found that the estimated dollar amount of the damage in New Zealand is 1.3% of its 2009 GDP. However, the majority of the damaged structures in New Zealand were considered historical buildings or resident houses in historical areas, and the damage was principally caused by non-structural components. The damaged structures and infrastructure were mostly within the city of Christchurch (GNS Science, 2010). In this, the country's second-largest city, the earthquake destroyed about 500 buildings and caused an estimated 930 million New Zealand dollars of damage (Withers et al., 2010). The remaining majority of land damage occurring in 400 farms in Canterbury plain was caused by ground liquefaction. The liquefaction resulted in major ground settlement (more than 300 mm in places), lateral spreading, and foundation support failure, with consequential building damage.

4.2 Social, Economic and Political History

New Zealand was a British colony until 1945. Initially, New Zealand was governed by the British. Slowly, New Zealand transformed into a self-governing country. Unlike the United States, New Zealand never declared independence from Britain. In fact, New Zealand remains a member of the Commonwealth Realm. Even though the country is self-governing, they still regard Britain as a social and cultural model, and the Queen of England as their queen: the "Queen of New Zealand."

Today, New Zealand is classified as a parliamentary democracy with a constitutional monarchy. In this type of system, the people elect members of parliament and the prime minister. Unlike the United States, the legislative and executive branches in New Zealand are intertwined. This means that the prime minister works with parliament to pass legislations. The

British monarchy remains the official head of state, but his or her powers are limited by the country's constitution (Chapman et al., 1999).

New Zealand is a country with a population of about four million people. Three-quarters of the population are European, and the rest of the country is comprised of immigrants from other Pacific islands and Asia, as well as the natives, called the Māori. Like their European counterparts, New Zealand's population growth was due to an influx of immigrants moving into the country (Wilson, 2009). Also, New Zealand's population is aging since fewer people are having children. For the most part, the different groups of people manage to coexist. Overall, New Zealand is a very stable country.

New Zealand enjoys a high standard of living. The country boasts a high number of educated people. However, New Zealand is not immune to economical problems. Unlike Chile, these problems did not destabilize New Zealand's government. But from 1950 to the early twenty-first century, the country has experienced the unsteadiness of its economy. One of the noticeable periods of economical instability was the collapse of the Korean War commodity boom, in the early of 1950s, which marked an unfortunate turning point in New Zealand's economic history (Singleton, 2010). Despite this uncertain period of time, the New Zealand government had always looked for economic partners to ensure the stability of the country. Along with reforms within the government, New Zealand recovered from their economic troubles in the 1980's (Easton, 1994). Rather than having government control each aspect of the economy, the government decided to stand aside and let the private sector contribute to the economy. This model is similar to the American economy. The economy of New Zealand began recovery toward the end of 1991. With a brief break in 1998 due to the Asian financial crisis, strong growth persisted for the remainder of the decade. By the early 2000s, New Zealand's GDP per capita was in the bottom half of the developed world (CIA, 2010)

4.3 Building Code and Enforcement

New Zealand benefited from a modern structural code and rigorous enforcement. In term of risk management, New Zealand has controlled their infrastructural and lifeline vulnerability to natural hazard with regional planning, improvements in local government and utilities preparedness since 1995 (EERI, 2010c). Even with a modern building code, New Zealand was not immune to the damages caused by the earthquake that struck the country in 2010. As mentioned above, the majority of buildings damaged at Christchurch were unreinforced masonry. This damage occurred despite a 1968 nationwide ordinance in which Christchurch implemented regulations that required owners of unreinforced masonry buildings to upgrade their building to at least 33% of the capacity required by the code if there was a change of use of the building. That is why some unreinforced masonry buildings in Christchurch had been upgraded (ASCE, 2010). Additionally, at Christchurch, there was significant damage done on the nonstructural components and contents that left many buildings inoperable—negatively affecting the country's economy (EERI, 2010c).

New Zealand, unlike Chile and the United States, enacted a "performance-based code" in their country rather than a specification-based building code. A Performance-based code is a guide on how a building and its components must perform to achieve the criteria. The difference between this and the traditional specification-based building code is that the traditional code would list the requirements an engineer must meet in order to comply with the code, while the performance code sets out objectives to complete. A performance-based code is not a particular recipe, but an idea—many recipes that are put together over a period of time. This code simply lists the goals of the building (i.e., the building ought to remain standing after an earthquake). Unlike a formal recipe, this code does not specify how to achieve the goal. This idea evokes the creativity of the designer, for he or she is not restricted by the lengthy list of ingredients to come up with a unite design for a particular building. A performance-based code is not more dangerous than a formal code. Rather, a performance-based code is a different way of thinking about risk and a society's vulnerabilities to natural hazards. Rather than thinking about risk management in the form of assumptions and equations, in performance-based engineering, objectives are set and it does not matter how one achieves the objectives of the design; the important thing is to achieve the goals put forth by the code. The building code in New Zealand was developed over a long period. In order to enact the code, engineers observed the aftermath of communities after many past earthquakes, and then observations were made in order to form a guide for future engineers to use. The New Zealand Code is divided into clauses, and each clause begins with an objective that states clearly what the goal is. Specific performance criteria for each clause then describe the extent to which the building must meet those objectives.

4.4An aftershock Mw 6.3 in February 2011

Impact of natural hazard events is comprised of magnitude and frequency (Pelling, 2003). The earthquake on February 22nd, 2011 in New Zealand is an example of this concept. The frequency of the earthquake impacted significantly and caused much more damage compared to the earthquake that happened on September, 2010. The intensity of shaking in the 2011 earthquake was stronger and caused a death toll of 160 and 80 still missing (BBC News, 2011). The magnitude aspect has been covered throughout the paper, while the frequency aspect is most significant in this example. The February 2011 earthquake was measured as a magnitude Mw6.3 which struck Christchurch again at 12:51 pm local time (2011-02-21 Coordinated Universal

Time). The epicenter was located approximately 10 km south-east of Christchurch, near Diamond Harbour, Lyttelton with a considered shallow depth of less than 5 km. The shallowness character, closeness of rupture to urban center and the timing of the occurrence had meant that the quake was particularly devastating (EERI, 2011d). The estimate for this damage during the quake is roughly 8-10% of the entire country gross domestic product in 2010 (USGS, 2011e). The largest vulnerability building types subjected in this damage are reinforced masonry and concrete block masonry constructions (USGS, 2011e)

As mentioned previously, the aftershock happened with closer rupture distance and relatively large magnitude, these two factors are significantly important. It is important to recall here an attenuation relationship, which is a function that is used to estimate different measures of ground motion intensity as a function of magnitude and distance. There are two factors significantly involved in the attenuation as seen in the following equation:

$$\ln(Y) = b_1 + b_2(M+6) + b_3(M+6)^2 + b_5 \ln(r) + b_v \ln\left(\frac{V_S}{V_A}\right) \qquad \text{(Eq 4.4-1)}$$

(Boore, Joyner, and Fumal, 1997)

where:

Y is the ground motion intensity (horizontal Peak Ground Acceleration or pseudo acceleration response S_a).

M is the magnitude of the earthquake.

b_1, b_2, b_3, b_5, b_v are regression coefficients based on the fault types of rupture.

v_s is coefficient on the condition of soil/site condition (geological and geotechnical conditions).

r is distance to source of rupture.

v_A is a constant.

In addition, the duration of ground motion is also essential. The duration is the amount of time that the peak value occurrence takes place, or the number of times the peak value of acceleration occurs within the earthquake. Clearly, these are the issues that the above attenuation does not account for. While the attenuation considers a structure subjected to a single peak value of ground acceleration, it actually experienced many such accelerations.

4.5 Summary:

The 2010 earthquake in New Zealand was 1.25 times stronger as compared to the earthquake that happened in Haiti, but the damage in Haiti was much worse. The challenge New Zealand faces at this time is how to maintain or even improve their code and enforcement to ensure their people will not be in danger during any natural hazards as well as to reduce the amount of damage caused. Despite the damage from the recent aftershock, New Zealand stood out as a country with high hazard resistance (USGS, 2011e). It is essential to mention that the country's resistance capacity reflects economic health and the system of maintenance within it. This capacity helps the country to withstand the impact of natural hazards. So New Zealand's path leading to improvement of an already successful maintenance program was not only to target disaster vulnerability, but also to focus on the wider goals of economic, social and political inclusion. Yet, structural enforcement of such a building standard is as crucial as the mentioned path. Has New Zealand achieved a reduced amount of damage, especially from unreinforced masonry and non-structural component failures? The answer is: not yet. Maybe the country needs to even further improve its building code targeting this aspect. Because of this reason, an overview to see how a different country would deal with unreinforced masonry structures is significant. In the following part, an overview of the unreinforced masonry act enacted in California will be presented.

4.6A view of America in Un-reinforced masonry structures: the Unreinforced Masonry Building Law of 1986

4.6.1 Introduction.

The outcomes of three major earthquakes occurring in 2010 in the countries of Haiti, Chile, and New Zealand included catastrophic failure or damage of unreinforced masonry structures (URM). This significant amount of damage created a motivation to know how a country with seismic code provisions would treat unreinforced masonry structures. California is a state with certain regions that have extremely high seismicity. In the following part of the paper, a review of the view and attitude toward URM buildings in areas of high seismic risk will be made. Studying California's URM Act does not imply that the Act should be the model role to look after. It is actually to find out whether the Act itself has achieved positive results or not. Thus, from the results one can quantify which action can be relevant to reduce damages from URM failure in the future.

4.6.2 The Unreinforced Masonry Building Law of 1986

Over the years, American seismic engineers have been seeking to provide the world the most proficient way of dealing with earthquake's damages. Building codes and laws seek to protect lives, while trying to minimize damages caused by earthquakes. Such codes are often developed in response to poor performance by structures during earthquakes. For instance, from 1868 to 1994, California suffered from major earthquakes such as Hayward (1868), Kern County (1952), Loma Prieta (1989), and others. Unreinforced masonry (URM) structures appeared to be greatly affected by earthquakes, generally performing poorly. This poor performance in the 1933 Long Beach earthquake drove a change in California building codes, no longer allowing URM buildings to be constructed (Hess, 2008). However, many URM structures in Seismic Zone 4 regions remained, and in 1986, a law was passed to address the public safety risk posed by these structures. This law, Senate Bill 547, became known as the unreinforced masonry (URM) law (EERI, 2004)

To help understand the motivation for the URM law in the state, it is important to remember why URM is considered a dangerous material for structures in seismically active areas. Masonry is constructed from units, historically brick or stone, bound together by mortar. Masonry materials are brittle, and can support very little tensile loads, if any. Like concrete, masonry structures depend on reinforcing, usually in the form of steel bars, to carry these forces. The ground motions caused by strong earthquakes can be enough to produce cracks, significant deformations, separations, cause units or even sections of walls to disconnect and fall, and even total collapse (Hess, 2008).

The URM law creates a program that aims to increase public safety and decrease the damage caused to URM structures during earthquakes (Hess, 2008). The law requires each local government within Seismic Zone 4 to:

a) Identify all potentially hazardous buildings in their jurisdiction by 1990.
b) Establish a mitigation program for hazardous buildings.
c) Report all information from (b) and (c) to the Seismic Safety Commission (SSC).

(Calf. Government Code, 2009; FEMA, 1999)

The SSC recommends that mitigation programs include retrofits such as removal or bracing of parapets, anchoring URM walls to roof and floor framing, bracing walls that do not meet height to thickness requirements for stability, developing horizontal diaphragms to control relative displacement, and developing in plane strength of walls to control inter-story displacements. Even though experience has shown that retrofitting URM buildings reduces both damage and loss of life, some local governments have adopted voluntary or “notification only” programs (Hess, 2008).

There were four types of URM programs in 1986, which were categorized as: Mandatory Strengthening, Voluntary Strengthening, Notification Only, and Other. Mandatory Strengthening requires strengthening in the building based on the City of Los Angeles Division 88 ordinance. The ordinance requires retrofitting and improvement of buildings with URM bearing walls. This program is described by the SSC as the most effective program type. Voluntary Strengthening requires owners to evaluate the risk in their building. The owner describes to their local governments the risk of their building and the time when they intend to retrofit. Notification Only involves the building owners receiving notification from the local government stating that their buildings belong to the building types known to exhibit poor performance in earthquakes. This program is described by the SSC as the least effective program type. Other similar requirements could be made by the cities or local governments. Examples ranged from requiring owners to post on the URM building a warning card to inform occupants and passersby of the earthquake threat, to various levels of strengthening (CSSC, 2003).

The California Seismic Safety Commission made recommendations to the State Legislature in 2006 based on the results of information reported to the SSC in item (c) of the URM law. Its recommendations included strengthening of all URM buildings, incentives to encourage building owners to retrofit, adoption of the International Existing Building Code as the State’s model building code, and establishing retrofit standards and programs for other building types that are also vulnerable to collapse during earthquakes such as soft-story, tilt-up, and older concrete structures (CSSC, 2003).

Although demolition exists as an option for jurisdictions with hazardous buildings, this method is rarely used, if only as a last resort, with most choosing to work with owners to retrofit rather than tear their buildings down. Because retrofitting measures are often expensive, it may seem that demolition would be a more efficient option; however, since the option is usually left to building owners, this is rarely done. Additionally, nearly all URM buildings in these communities were built before 1933, located in historic districts, and often considered historic themselves (EERI, 2004). The disruption caused in a historic area by demolishing a building may be undesirable to the community. Further, if the building itself is historic; it is more desirable to the community to keep the building by retrofitting rather than losing it by demolition.

The URM law has not generally received strong opposition, in part because the law give the authority to individual communities to decide what programs will be used an how they will be enforced. Those which chose mandatory retrofit initially received opposition from some building owners, due to costs of strengthening and additional taxes on the increased value of the building. This opposition ended, however, when the 1994 Northridge earthquake demonstrated the benefits of upgrading the hazardous buildings (Hess, 2003).

Some people feel that the URM law does not go far enough to protect public safety because it allows local governments to choose their own mitigation program and does not require retrofit except under the “Mandatory Strengthening” program, if chosen by the jurisdiction. Some jurisdictions are still operating under a “Notification Only” program, which requires only a posted warning describing the danger of an URM structure during the earthquake, and posting this warning is the responsibility of the building owner. Additionally, cosmetic coverings that change building appearance and lack of enforcement have allowed non-compliance with this type of program (CSSC, 2004; Grossi and Muir-Wood, 2006).

Despite the lack of enforcement by some communities, general compliance with the law as a whole is very high, with less than 1% not yet completing URM inventories and about 98% of URM structures in mitigation programs (CSSC, 2003). The data from the SSC show a high level of compliance with the URM law, and important work has been done to establish URM building inventories and retrofit in the jurisdictions that have chosen such a program. Without requiring retrofit in all the affected communities, however, adequate steps have not been taken to ensure each URM building is safe during an earthquake. In order for people to describe the URM law as successful, the law should incorporate the SSC recommendations of requiring mandatory retrofit programs, and adoption of the International Existing Building Code, so that upgrades are made in compliance with the latest standards.

Chapter 5

Case study of the Former US Embassy

Chancery Building Office, Port- au- Prince, Haiti

Introduction

Although many buildings failed after the earthquake in 2010, Haiti, the Chancery Office Building, U.S Embassy in Port-au-Prince stood out with only minor damage (DesRoches, 2010). This building received strengthening after J.R Harris & Company prepared a seismic Evaluation Report in 1995. To understand and possibly provide the view of past evaluation, a model for this building was built in computer structural software called MIDAS. A comparison between the seismic evaluation of the structure in 1995 and the evaluation model was made.

The case study includes an analysis and design of a two story concrete moment resisting frame building located in Port-au-Prince, Haiti. The illustration of the structural part includes applications of ASCE 7-05 design provisions and ACI318-05. The design process began with the determination of the loads and appropriate load combinations. Then, the period of the building was checked after applying those loads to the MIDAS model. Then the beam and column members were selected in accordance with the strong column weak beam philosophy. For these selections, the seismic check included the story drifts, and the stability coefficients were needed to verify that the selections made were valid.

5.1 Background of the structure's seismic evaluation in 1995

Written by J.R Harris & Company, Structural Engineering, the report presented an evaluation of the structure against criteria for seismic performance following the NEHRP Handbook for

Seismic Evaluation of Existing Buildings (FEMA 178), and designed upgrades to meet the requirement of Recommended Provisions for the Development of Seismic Regulations for New Buildings (FEMA 222), 1991 edition as well as modify the existing structural elements to meet the criteria in FEMA 178. The Chancery building is a two story reinforced concrete special resisting frame with stone masonry infills, and stiffened steel panels were added as a result of Harris' strengthening plan. Partitions consist of concrete and concrete block walls. The building is reported to have been constructed on land reclaimed from the bay and is supported on concrete (and some wood) friction piles that are 30 to 40 feet long. The ground floor is a reinforced concrete structural slab-on-grade. The 2nd floor and roof slabs consist of reinforced concrete joists and beams with concrete block fillers. The span lengths of the structural concrete members are listed in Table 5-1.

Member type	**Direction**	**Length**
Joists	North-south	5120 mm (16.8 ft)
Beams	East-west	8960 mm (29.4 ft)

Table 5-1. Structural members spans

The roof plan showing the member spans is illustrated in Figure 5-1. The plan form is rectangular with two interior courtyards. Most interior partitions are concrete masonry with plaster (Table 5-2). The exterior cladding at the second story is an infilled panel of glass and light gage steel sheets built on a frame of small steel tubes. Three types of cladding are used at the first story: the original panels similar to the second story exist at the interior courtyards, and some bays are infilled with a thick panel of random field stone. The original panels on the remainder of the exterior have been replaced with steel and glass panels of structural grade plate and heavy tubes combined with security glass.

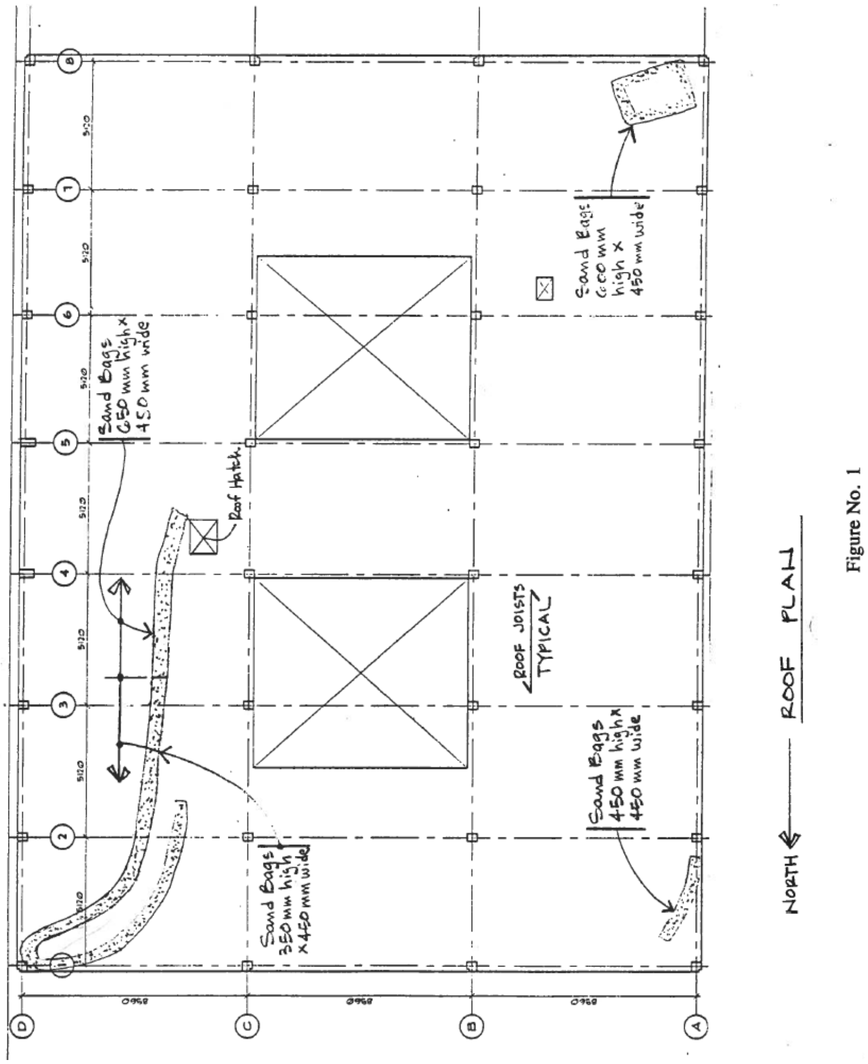


Figure 5-1. Roof plan view.

Wall Location	**Type**
Exterior	Double wythe stone (335 mm thick), stiffened steel panel (2 layers of ¼” steel plate on frames of 6”×4” and 4”×4” steel tubes), and window/wall façade.
Interior partitions	100 mm concrete block with some reinforcement and 100 mm unreinforced concrete at upper levels.

Table 5-2. Wall location

5.2 Material properties

5.2.1 Concrete

f'_c	3000 psi = 20.6 MPa

E	21.5 GPa
ν	0.3
w	22.8 kN/m^3
m	2300 kg/m^3

Table 5-3. Concrete properties

5.2.2 Steel

f_y	275 MPa
E	200 GPa
ν	0.3

Table 5-4. Steel Properties

5.2.3 Stone Infill

E	20.7 GPa
ν	0.25
w	25.1 kN/m^3
m	2562 kg/m^3

Table 5-5. Stone Infill properties

5.2.4 Infill Masonry

E	10.3 GPa
ν	0.25
w	17.0 kN/m^3
m	1730 kg/m^3

Table 5-6. Infill Masonry properties

5.3 *Loads*

Self weight values of building materials are given in tables below:

5.3.1 Second Floor

Partitions	40.0	psf
¾” Terrazo	9.4	psf
2 ½” Slab	31.3	psf
12”×4” Joists @ 20” o.c.	30.0	psf
Form Blocks	21.8	psf

1” Plaster Ceiling	12.5	psf
Arch., Mech., Misc.	5.0	psf
Total Dead Load	**150**	**psf**
Live Load	**25**	**psf**

Table 5-7. Self-weight of building materials in second floor

5.3.2 Roof

Roofing	21.0	psf
2 ½” Slab	31.3	psf
10” ×4” Joists @ 20” o.c.	24.6	psf
Form Blocks	20.0	psf
1” Plaster Ceiling	12.5	psf
Arch., Mech., Misc.	5.0	psf
Large Mechanical Units	5.0	psf
Total Dead Load	**119.4**	**psf**
Live Load	**10**	**psf**

Table 5-8. Self-weight of building materials in roof

5.4 Description and commentary of evaluation and design

The original analysis by Harris in 1995 was performed using FEMA-178, *NEHRP Handbook for the Seismic Evaluation of Existing Buildings*. Where seismic retrofit was necessary, criteria given in FEMA-222, *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings* was used. Analysis in MIDAS was performed using ACI 318-89 which chosen to be suitable according to the period of construction. Reinforcement design was performed using ACI 318-89 in the original analysis by Harris. Checking in Midas for design also used ACI 318-89. From Harris’s evaluation, the building was built based on a smaller response spectrum of ground acceleration (see Figure 5-2), while after the 2010 earthquake, USGS reported a larger response spectrum (see Figure 5-3). Strengthening design is therefore needed to satisfy the new spectrum analysis. This strengthening design analysis uses ACI 318-05.

5.4.1 Design response spectrum

The design response spectrum was then obtained from the Harris’s evaluation, shown below.

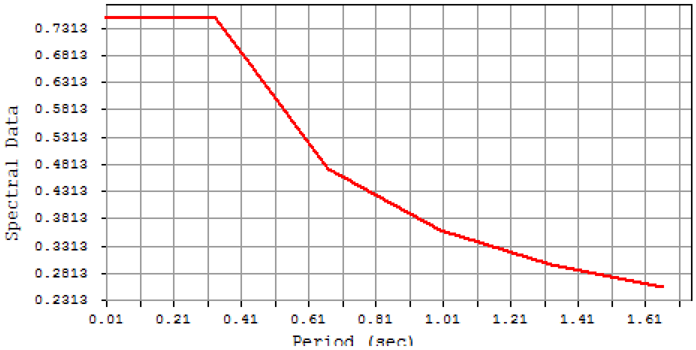


Figure 5-2. Harris's evaluation design response spectrum curve.

In order to find the seismic design catefory of the site, a spectrum analysis is done on the USGS program (found at http://earthquake.usgs.gov/research/hazmaps/design/index.php). The curve is shown in Figure 5-3 below.

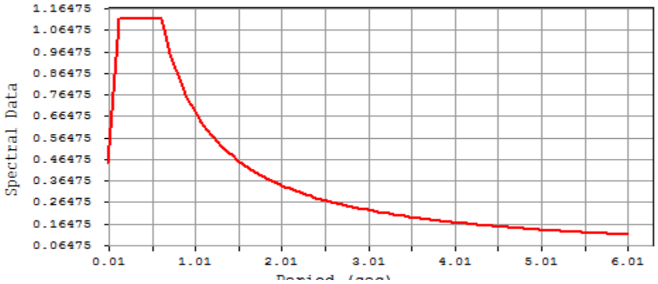


Figure 5-3. Design response spectrum using USGS (2010) spectral data.

Clearly, the two design spectrum curves are quite different. It is interesting to recall that the structure was reportedly only subjected to minor damage despite the difference between the design earthquake and the one that actually occurred.

5.4.2 Seismic coefficients

Based on Table 12.2-1 in ASCE 7-05, the response modification coefficient R was found to be 8. In addition, the occupancy category of the building is‘I’, with an importance factor of one, from

Section 11.5.2 in ASCE 7-05. The seismic design category was found to be category D based on the S_{DS} and S_{D1} values from Table 5-9 and Section 11.6 of ASCE 7-05.

Location and mapping coefficients:		Units	Reference
S_s	1.069	g	*USGS,2010*
S_1(s)	0.68	g	*USGS,2010*
Site class D		ASCE11.4-1	*USGS,2010*
F_a	1	g	ASCE11.4-1
F_v	1.5	g	ASCE11.4-1
$S_{MS}=F_aS_s$	1.069	g	ASCE11.4-1
$S_{M1}=F_vS_1$	1.02	g	ASCE11.4-2
$S_{DS}=2/3S_{MS}$	0.713	g	ASCE11.4-3
$S_{D1}=2/3S_{M1}$	0.68	g	ASCE11.4-4

Table 5-9. Seismic mapping coefficients

5.4.3 Loads and Load Combinations:

The next step in the design process was to determine the appropriate load combinations to be used for the building. There are two load combinations that include seismic loading:

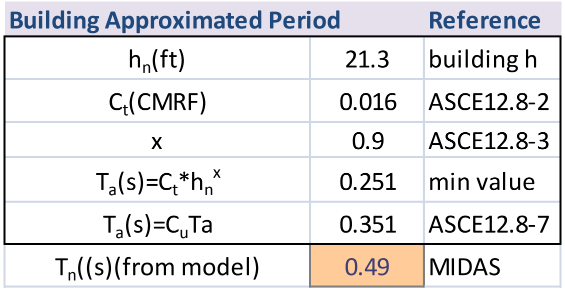
$$(1.2+0.2S_{DS})D+\rho Q_E+L+0.2S \quad \text{(controlling equation)} \qquad \text{(Eq 5.4.3-1)}$$

$$(0.9-0.2S_{DS})D+\rho Q_E+1.6H \qquad \text{(Eq 5.4.3-2)}$$

Load Combinations are based on strength design (LRFD) from section 12.4.2 in ASCE 7-05. Both load combinations include a redundancy factor ρ for the seismic load Q_E. In this building, ρ is equal to 1.3 (from ASCE 7-05 section 12.3.4.2 for seismic catergory D). Combination (Eq 5.4.3-1) was found to be the controlling load combination and it was used in the design calcualtions as well as in the MIDAS model. Load patterns including seismic and self-weight loads are presented in Appendix 4.

5.4.4 Period Check

The buidling model in MIDAS was built, and then the period from this model was obtained. Seismic coefficients were input into the model as well as the ground motion coefficient from the earthquake. The approximate period according to the code was computed as T_a=0.251seconds. This period value was used for the equilvalent lateral force (ELF) method together with the seismic coefficient to find the seismic force distribution in each floor. The period found in the MIDAS model was 0.49 seconds for the fundamental mode (see Table 5-10). The fact that T_a was used even though it is less than the period from the model was because the intention was to conservatively design the building with lager forces.



Building Approximated Period		Reference
h_n(ft)	21.3	building h
C_t(CMRF)	0.016	ASCE12.8-2
x	0.9	ASCE12.8-3
$T_a(s)=C_t*h_n^x$	0.251	min value
$T_a(s)=C_uTa$	0.351	ASCE12.8-7
T_n((s)(from model)	0.49	MIDAS

Table 5-10. Approximate periods

5.4.5 Base Shear and Story Forces

The next step was to determine the building shear forces to compare them with the output building shear forces from the MIDAS model. In order to determine the shear forces at each floor, the equivalent lateral force procedure was used based on section 12.8 of ASCE 7-05. The period used in this process was 0.49 seconds and the k coefficient in the equations for the vertical distribution factor of story forces (C_{vx}) was taken as 1 according to ASCE7-05 equation 12.8-12. Using the designated period, the importance factor, the response modification coefficients, S_{DS}, S_{D1}, and S_1, the seismic response coefficient was calculated based on section 12.8 of ASCE 7-05.

Calculations for this coefficient can be seen in Table 5-11 below.

Shear Force at each Floor			**Notes/References**	
k=	1		ASCE 12.812	
Vs=	**378**	kips--->	**BASE SHEAR**	
Floor	**h(ft)**	**W(kips)**	**$W_x h_x^k$**	**C_{vx}**
Roof	21.6	1141	24645	0.70
1st Floor	10.3	1037	10683	0.30

Table 5-11. Base shear coefficients

The base shear was determined to be 389 kips for the whole building. As seen below, in table 5-12, the distribution of shear forces is also computed for each floor. Accidental torsion also needed to be considered in the shear forces. To account for this torsion, the shear force was increased by 5%. For this building, since it is rectangular, the center of mass is in the same location as the center of rigidity. This means that there are no torsional irregularities in this building therefore, torsion amplification is not necessary. Table 5-12 and 5-13 list the calculated story forces and the output of story forces from MIDAS. As seen in Figure 5-4, the seismic forces acting at the rigidity center of the building:

Base Shear Force:	**Value**	**Units**	**Notes/References**
W-roof	1141	kips	*beams carry selfweights*
W-floor	1037	kips	*beams carry selfweights*
W-total	2178	kips	ASCE 12.8.1
Vs,base	378	kips	Cs*W

Table 5-12. Base shear hand calculation

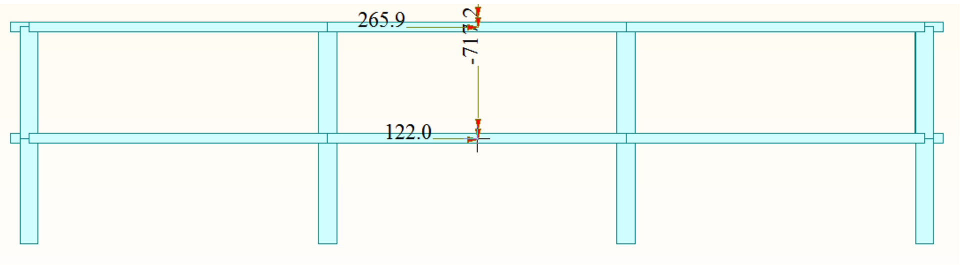


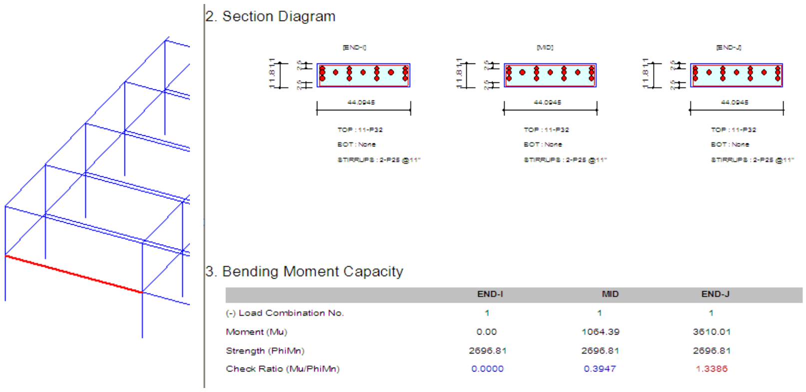
Figure 5-4. Distribution of story forces

The story forces were then compared to hand calculations to ensure the accuracy of the model. Shown in table 5-13 below the results of hand calculation for story force (F) and the model story force (Fmodel).

Floor	F(kips)	1.05*F(kips)	Fmodel(kips	%Difference
Roof	264	277	266	4.0
1st Floor	114	120	122	-1.7
BASE SHEAR	378	397	388	2.3

Table 5-13. Comparison of hand calculation and model forces.

Since the two results are close to each other at this point, it is not necessary to further obtain all the calculations by hand. At the time of the evaluation, J R Harris Co had included the concrete walls as well as the steel panels in their analysis, and the impact of these wall added a significant rigidity to the building. The fact that the building experienced only minor damage means it must have received some help from these walls. Yet, when modeling this building, all the walls were taken out so that the analysis was solely focused on the frame structure itself. Consequently, as a result of this simplification, the displacement check for the frame did not meet the code requirement. Although, it appears that the safety factor when the building was built had also helped the building as well, based on the fact that it was only subjected to minor damage. Seen in Figure 5-5 below is one of the capacity checks of a beam member chosen at random.



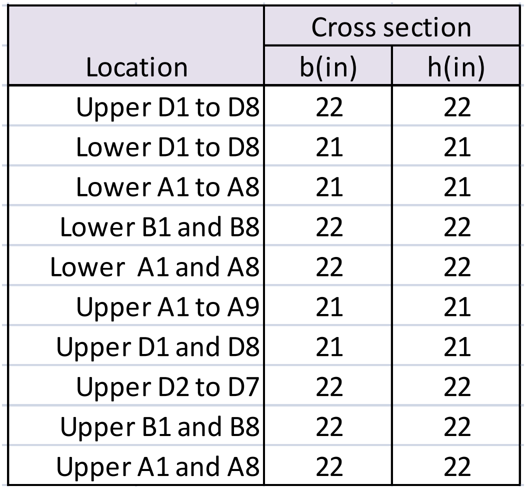
3. Bending Moment Capacity

	END-I	MID	END-J
(-) Load Combination No.	1	1	1
Moment (Mu)	0.00	1064.39	3610.01
Strength (PhiMn)	2696.81	2696.81	2696.81
Check Ratio (Mu/PhiMn)	0.0000	0.3947	1.3386

Figure 5-5. Random capacity check of a beam member

5.4.6 Member Selection

The model was run with the new response spectrum design requirement and with the focus solely on the frame. Displayed below is the proposal for a new design which satisfied the new spectrum, drift requirement, and strong column weak beam philosophy. For the sake of completeness, these beams and columns were optimized to meet the code requirements. For some columns, the strict newer code requirements for story drift required the section geometry to be changed. Shown in the following table 5-14 are the newly designed members. Optimized design is beyond the scope of this case study, therefore it should be the topic for further studies.



	Cross section	
Location	b(in)	h(in)
Upper D1 to D8	22	22
Lower D1 to D8	21	21
Lower A1 to A8	21	21
Lower B1 and B8	22	22
Lower A1 and A8	22	22
Upper A1 to A9	21	21
Upper D1 and D8	21	21
Upper D2 to D7	22	22
Upper B1 and B8	22	22
Upper A1 and A8	22	22

Table 5-14. Designed section geometry for all columns

Shown in Appendix 6 and 7 are the reinforced design for beams and columns. A challenge in the design is that the story drift was large after amplifying by C_d=5.5. Because of this, the members selected are rather large in order to withstand the earthquake. MIDAS has an option that checks the story drift for each trial of the selection, as seen in Figure 5-6 and Table 5-15 below. These parameters are matched with the code requirement of the allowable drift. Strong column-weak beam requirements are also checked in Appendix 8 prior to the selection.

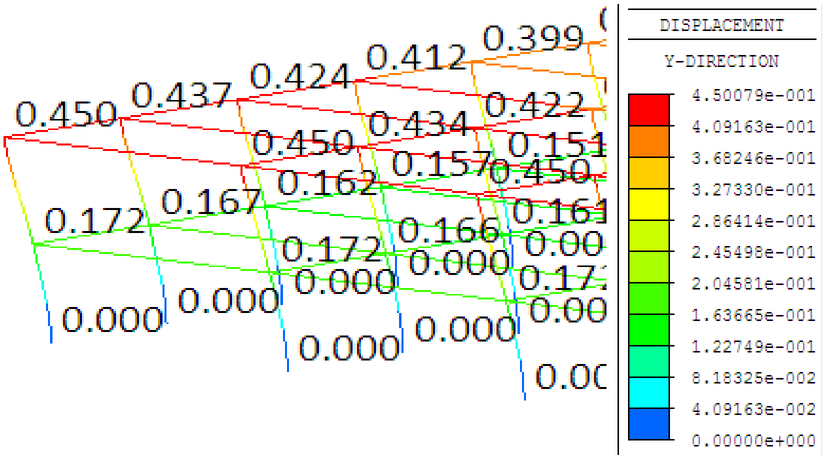


Figure 5-6. Displacements for story drift check

The ratio of allowable story drift for Occupancy Category I for this type of structure is required to be less than 0.02 times the story height according to Table 12.12-1 in ASCE 7-05. Table 5-15 and Appendix 5 show that for both Floor 1 and the roof, this value is below 0.02.

Story Drift(in)				
Story	ELF $_{model}$	MRSA $_{mode}$	ratio(EFL)	ratio(MRSA)
Roof	0.278	0.169	0.012	0.007
Floor 1	0.172	0.100	0.007	0.004

Table 5-15. Story drift.

5.5 Conclusion

Through the use of the equivalent lateral force method, the shear forces at each floor were determined and compared to the results from using modal analysis. These forces were then input into MIDAS, allowing for the member sizes to be determined. Checks were made to ensure that the required strengths were met along with the seismic requirements from the code. The checks resulted in the member sizes being increased significantly to make them seismically sufficient. Based on the calculations discussed in this part, the structural design of this two story CMRF building is properly designed to take into account the high seismic load found in Port-au-Prince, Haiti. The building has been designed to resist the hierarchy of failure modes by sizing the members appropriately to control the relative strength of members under these failure modes. It is beyond the scope of this part to see if the building designed in this report is cost-effective.

Although it had been previously strengthened before JR. Harris & Co’s proposal, the former U.S. Embassy building was found to have a number of deficiencies according to the new code requirements. The model created in Midas confirmed several of these weaknesses under seismic loading. Calculated strength values of frame members matched well with those obtained by MIDAS. The presence of infill walls provided a unique opportunity to study how the structure behaved with these elements, even though modeling their proper behavior is not well understood. It is clear that modeling these walls using wall elements in the software helps the structure, although in this case, still not enough to resist the design loads of this study. With this in mind, these walls are likely to crack under seismic loading, thus drastically reducing the amount of capacity they can contribute to the structure. An alternative for strengthening these walls with FRP may be offered, in order to allow these walls to contribute to the capacity more reliably. Overall, with the outcome of the results, understanding this recommendation was enhanced, although the reinforcing in stone wall and infill wall would also be interesting to consider.

Chapter 6

Comparisons and Findings

Different levels of risk that a community accepts depend on the type of economic, social, and political systems in place in the community, as well as their level of development. These three factors greatly influenced the reaction of Haiti, Chile, and New Zealand after the earthquakes that struck their countries. Understanding these unique differences between the accepted level of risk and the individual country requires engineers to analyze each country separately. As shown in Figure 6-1, for a specific risk, a framework is made to detail the many factors that come along with the risk, and it is up to the individual country to decide the acceptable level of risk that they can endure.

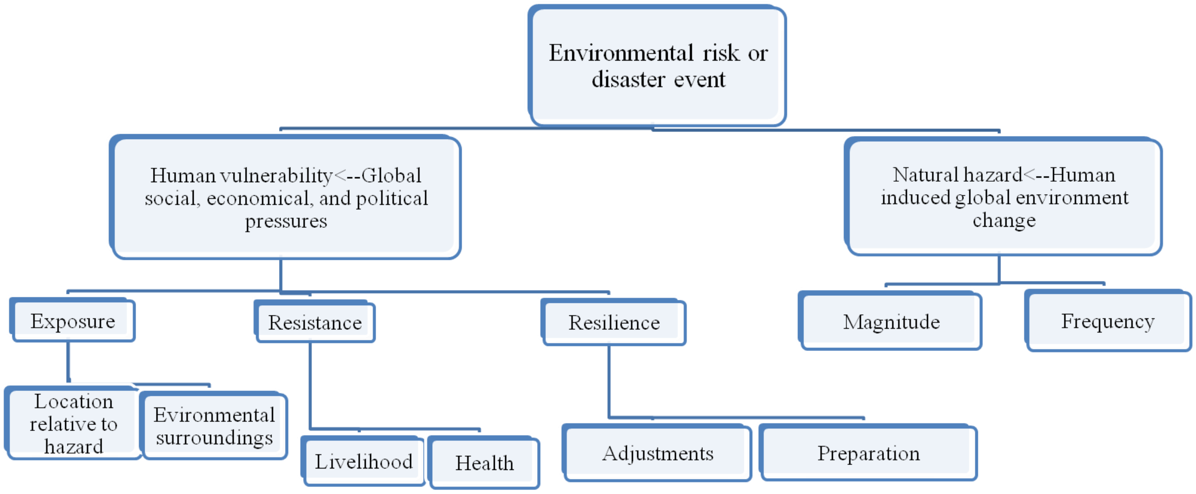


Figure 6-1. Components of risk. (Pelling, 2008)

In previous chapters, natural hazards, human vulnerability, and the exposure of the countries to natural hazards have been discussed. In this chapter, the rest of the risk components will be covered, and the parts determining them categorized. In contrast to exposure, which makes people susceptible to risk, the role of resistance and resilience capacity represents the capacity of the community to withstand impacts of hazards. As seen from Figure 6-1, these capacities come from the community's livelihood, health, adjustment, and preparation. Resilience capacity can only be enhanced if resistance within the society is high and exposure is lessened. In other words, human vulnerability can only be less impacted by risk when its exposure is reduced and its resistance and resilience capacities are significantly reliable (Pelling, 2010).

After a review of the literature presented in the previous sections, the differences among Haiti, Chile, and New Zealand appears clear. The differences indeed show a consequence between each country's economic, social, and political systems and its corresponding resilience capacity. The resilience of a country after a disaster depends on the history of physical, economic, social and political performance which took place prior to the disturbance (Corotis, 2010). Haiti's community is an example of poor resilience capacity in this case. Their economy, society, and government are very susceptible to the disruption caused by a natural hazard. To be able to measure the risk Haiti has faced in the past and analyze potential risks in the future is one of the ways to determine the resilience ability within the country itself. In this section of the paper, identification and analysis of the resilience capacity for the three countries--Haiti, Chile and New Zealand--will be made. Even though the resilience capacity is different in the three countries, one can draw a reasonable conclusion about the lessons each country can learn from problems that arose by a disaster. For Haiti, this will be to the driving-force to reconstruct the country or at least to identify who in the Haitian government would oversee the elimination of the factors that had pushed the country into the current situation. For Chile, the challenge is what should be improved so that natural hazard can be mitigated without any harm to the community or even without damage to structures. And lastly, for New Zealand, the country that overcame the 2010 earthquake the most successfully, the question is how to maintain such a high level of resilience of its society and how to continue to bring the country forward in the manner it has experienced in the past year.

This thesis has provided a picture of the susceptibilities of Haiti though looking at its social and political histories. Chile and New Zealand have provided two examples of countries that were able to establish meaningful dialogue between the different parties involved in the society to reduce risks and plan for future events. It is to Haiti's advantage to learn from Chile and New Zealand's history of code development, as to create its own meaningful way to establish dialogue between the different components of society and to mitigate the risk to disasters. This part will summarize the objectives and analyze the available information to conclude the urgent sustainability requirements for Haiti. In addition, there will be the general summary as well as the comments based on throughout comprised observations.

6.1 Relationship between damage after natural hazards and gross domestic product

The damage caused by the earthquakes in the three countries: Haiti, Chile, and New Zealand, is seen in Figure 6-2 below. This figure shows the relationship between the damage after a natural hazard (in this case, an earthquake) and the country's gross domestic product. This chart has used Gross Domestic Product (GDP) per capita as a measurement of economic activity per person within a country, reflecting the country's economic dimension. As the country's GDP increases, the cost of damage caused by the earthquake as a percentage of the GDP decreases dramatically. Damage estimation after the natural disaster is used as a percentage of GDP for the whole country. From this chart, one can easily see that the damage is reduced considerably when the economy of a country is vigorous. Indeed, one of the factors that led to Haiti's struggle after the earthquake was its weak economy. This means in order to reduce the risk toward natural hazard, the GDP of Haiti in particular, needs to be increased. A stronger economy would improve Haiti's capacity to devote resources to reduce the amount of damage experienced during natural disasters. As demonstrated by New Zealand, a country with a growing economy can recover more quickly from damage, so the highest priority efforts to enhance resistance capacity against risk are to develop the economy. Additionally, it is essential to adapt retrofitting specification as well as effective enforcement especially for historic (unreinforced masonry) buildings. The earthquake in 2011 indeed dramatically exposed the vulnerability of these structures (USGS, 2011) and increases the damage overall, as seen in Figure 6-2 below.

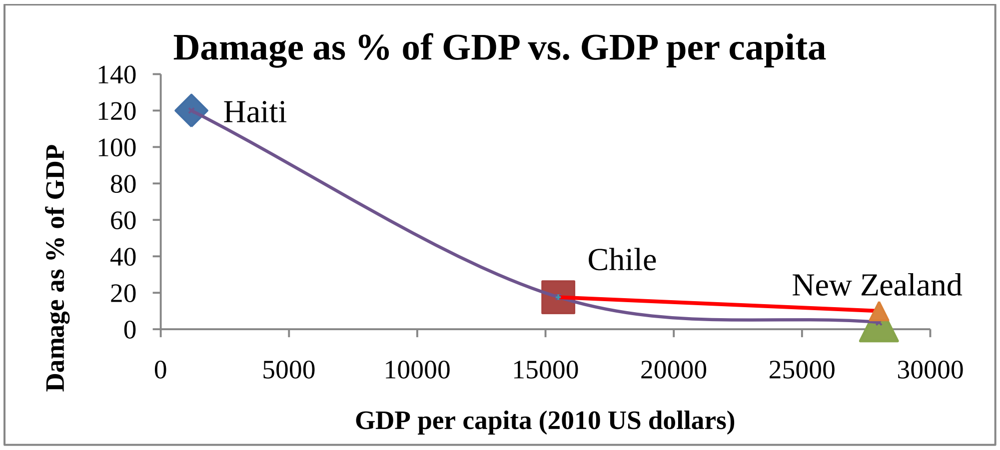


Figure 6-2. Relationship between damage and GDP per capita

The decay portion between Haiti and Chile seems exaggerated. A question to ask is how this portion of the curve ought to look like if there are more data added to the chart. Therefore, three additional earthquakes are analyzed: one in Peru, one in Algeria, and one in Turkey. In 1970, an earthquake with magnitude of 7.9 happened in Peru and caused 530 million US dollars in damage (EM-DAT, 2011). In 1999, an earthquake with magnitude of 7.6 occurred in Turkey and caused 40 billion US dollars in damage (Johnson, 2000), and in 1980, a magnitude 7.2

earthquake in Algeria caused 5.2 billion US dollars in damage (EM-DAT, 2011). The damage from the earthquakes in Peru, Turkey, and Algeria were then adjusted for inflation so that one can easily compare the results in the different countries. These three values were added onto the chart to see if there is a relationship, and the results can be seen in Figure 6-3. By adding more data to the chart, one can more clearly see the relationship between the result of the natural hazard and the various stages of economic development. Despite the fact that the damage in Peru, Turkey, and Algeria earthquakes were lower as a percentage of the country's GDP compared to Haiti's earthquake, it is worth pointing out here that the assessment of hazard damage in general is difficult. There were many earthquakes that were considered as destructive, but their corresponding damages in terms of number of dollars can only cover part of the description. As many others involved issues, such as: damages in surrounding areas, destruction of towns, destruction of community, and dislocation of numerous people, which are difficult to quantify in monetary terms.

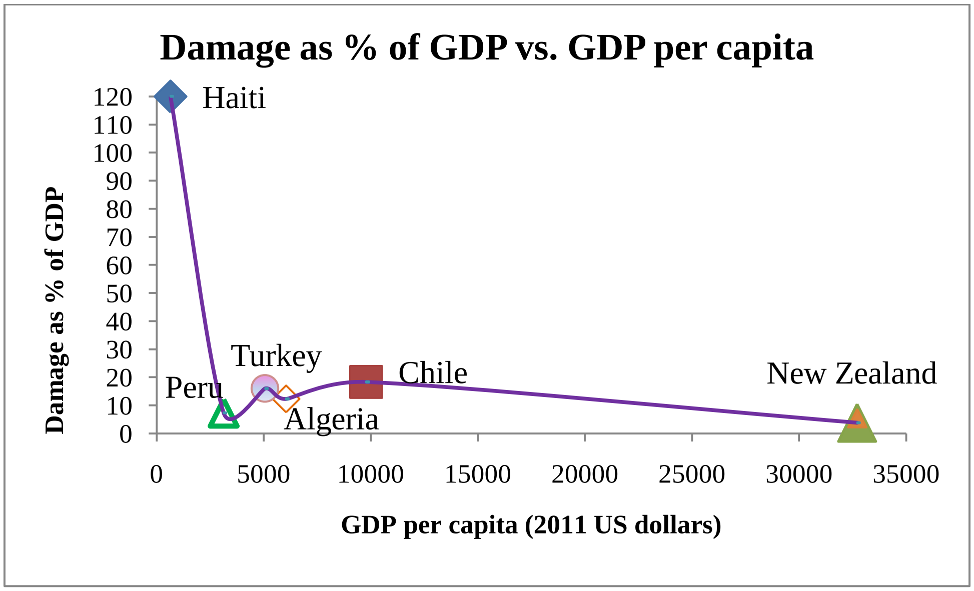


Figure 6-3. Damage as percentage of GDP versus GDP per capita with the additional information of earthquakes in Peru (1970), Algeria (1980), and Turkey (1999).

As shown in Figure 6-3 above, the damage in Haiti once again stood out dramatically. In particular, the damage from the earthquake in Haiti identified two specific facts: (1) the economy of the country itself is so meager, (2) the damage is quite extensive as compared to other countries. The idea behind choosing Peru's 1970 earthquake, Algeria 1980 earthquake, and Turkey 1999 earthquake here is to emphasize the vulnerability of Haiti with the stage of the country's economy. In 1970, the earthquake happened in Peru, the earthquake was considered one of the most destructive ones in the world (USGS, 2011f). Yet the damage from the earthquake caused nearly ten percent of the damage done in Haiti, despite the fact that Peru did not have seismic code provisions until after the occurrence of this earthquake (USGS, 2011f). Sharing the same situation of the absence of seismic codes in the building standard is Algeria (Bendimerad, 2004), shown in this chart, the damage in Algeria was 12.3 percent of the GDP of the entire country at the time of the hazard occurrence. Finally, the chart included the damage from the earthquake in Turkey (1999) with the idea of connecting the developing countries and the developed one in this comparison. While the results of the hazards in New Zealand were recorded in the two different events, one in 2010 and one in 2011. Yet, the curve is indeed dramatically decayed as the economy of the country is increased, but also with the stage of development of the building code itself. Three years after its earthquake, Algeria revised its seismic code (Bendimerad, 2004). Peru revised its seismic code seven years after its earthquake (Piche, 2007). In 1997, prior to the earthquake, the ductile provision for seismic design was revised in Turkey (NISEE, 2004). Damage in Turkey was relatively higher than Algeria and Peru due to the value of infrastructure. The Chile earthquake created a "kink" in the chart caused by the fact that the earthquake's magnitude is much larger compared to the others, especially since earthquake magnitude is measured on a log scale. In the horizontal axis, the GDP showed the economy of New Zealand is twice as large as that of Chile, and with the addition of the presence of the modern code, the damage was not as intensive relative to the compared countries.

Presented in Figure 6-4 below is Haiti's economy for a ten year period. As seen in this illustration, Haiti's economy increased slowly from 2004 to 2009. This trend was interrupted dramatically after the earthquake. Quite evidently, this disaster negatively impacted the country, but in this case, one can also argue that the slow growth of the economy itself over a long period of time actually left the country with a worse exposure to risk of disaster. So the country's sluggish GDP growth and its exposure to risk are a result of years of accumulated problems. Craig (2010) once described Haiti as "the country that time has left behind", and it now quickly needs to catch up in order to recover and prevent similar catastrophic events.

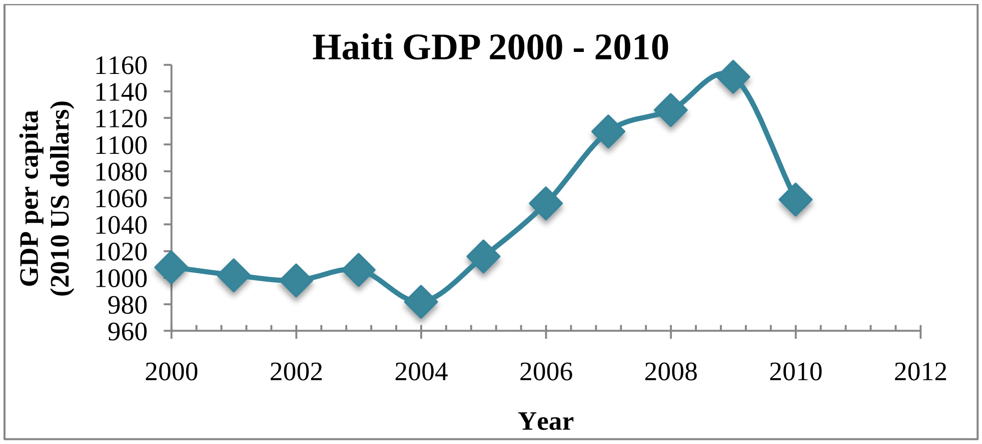


Figure 6-4. Haiti's GDP over the past eleven years.

6.2 Impact of politics on human vulnerability.

Economic strength provides information about the organizational capacity of the government in many aspects. It is worthwhile to look carefully into four specific drivers of growth in Haiti: agriculture and rural development, tourism, infrastructure, and science, technology and innovation. In addition, it is time for the Haitian government to realize that their system of management must be improved since corruption reached a considerable high for the country at the end of the year 2008. One more factor considered controversial at the time of this study is whether or not conditions in Haiti after the earthquake have been strongly exacerbated by corruption. Over many years, Transparency International (TI) has researched and surveyed to find an indicator measuring how a country exhibits an abuse of entrusted power for private gain or encompasses corrupt practices in both the public and private sectors. The Corruption Perceptions Index (CPI) is a scalar number that ranks countries according to the perception of corruption in the public sector; the CPI grade increases as the corruption is less within a country. The CPI is an aggregate indicator that combines different sources of information about corruption, making it possible to compare countries. The CPI number describes the possible reasons for an economy to stay mostly undeveloped over many years. The relationship of a country's economy is proportional to the CPI number, as shown in Figure 6-5. Haiti was graded as only 2.2 in the corruption perception index scale.

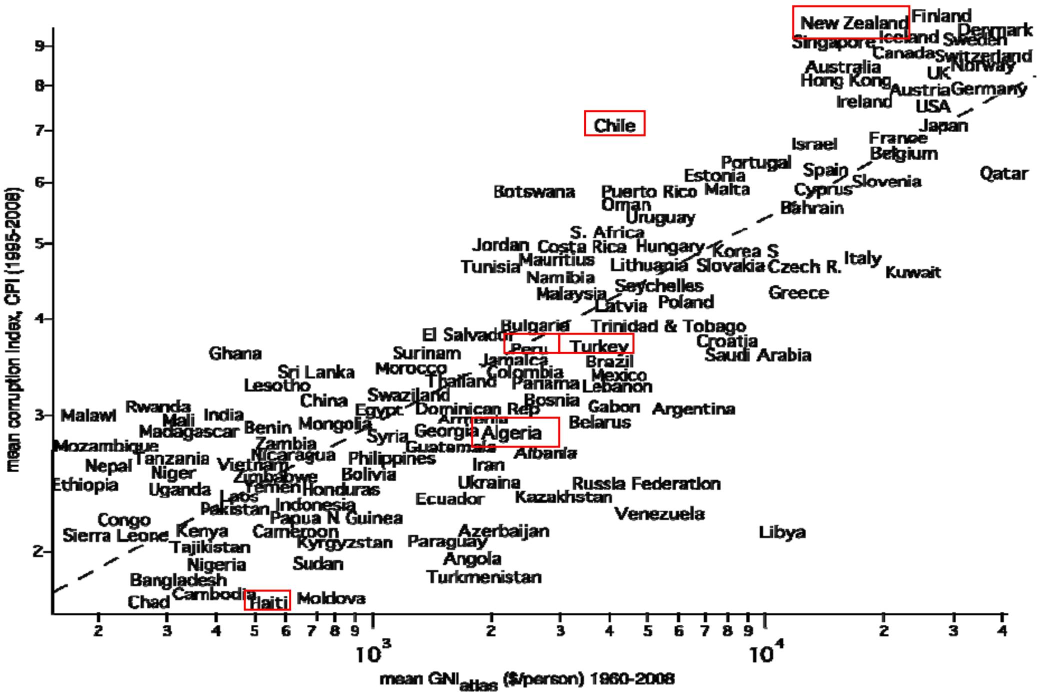


Figure 6-5. The mean corruption index CPI versus mean gross national income.

Haiti’s CPI is very low compared to every other country, making economic progress difficult. The main principle goal of this part of the discussion is to point out one essential recommendation for the Haitian’s government: the need for changing the system of manipulating and managing within their country. Clearly, the problems indicated here are totally out of engineers’ control. Yet, after any disaster, engineers are involved in the rehabilitation of the country and required to address the consequence. If in these plans, engineering professionals are to be effective with the Haitian public, they will need to be aware of their decisions with respect to the risk understanding aspect. Society’s awareness of sustainability as a whole is crucial, thus development in the short term and sustainability in the long term for Haiti’s future therefore must be addressed, so that the requirements of current needs and future development plans can become the gears that enable the resilience. By examining Figure 6-6 below, one can see that the amount of damage experienced during the 2010 was significantly higher in Haiti than in the other two countries, whose CPI numbers are much higher. This relationship should be considered one of the factors that affects vulnerability and risk of a country.

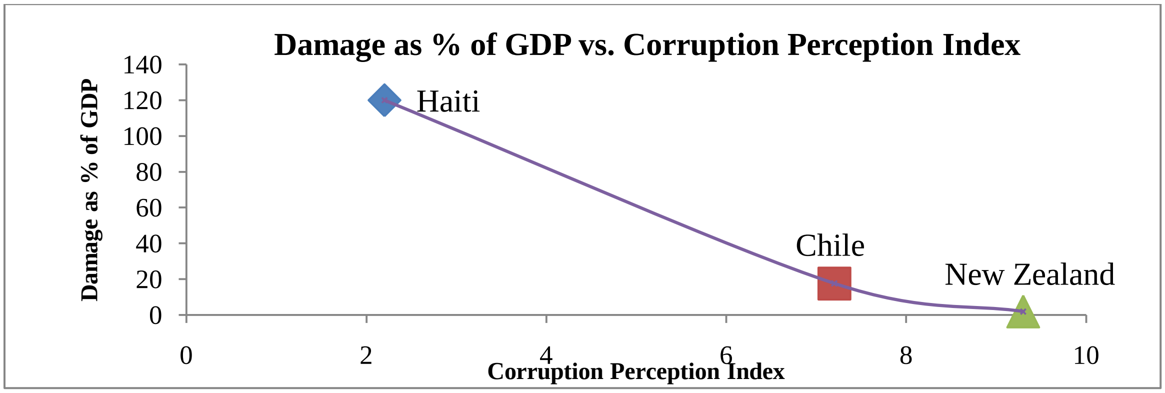


Figure 6-6 Damage as % of GDP vs. Corruption Perception Index

As mentioned in Section 6.2, comparison is needed to include more data. Therefore, three additional countries were added in between the portion of Haiti and Chile. Again, one can see the relationship of social's issue to the vulnerability stage of a country as in Figure 6-7.

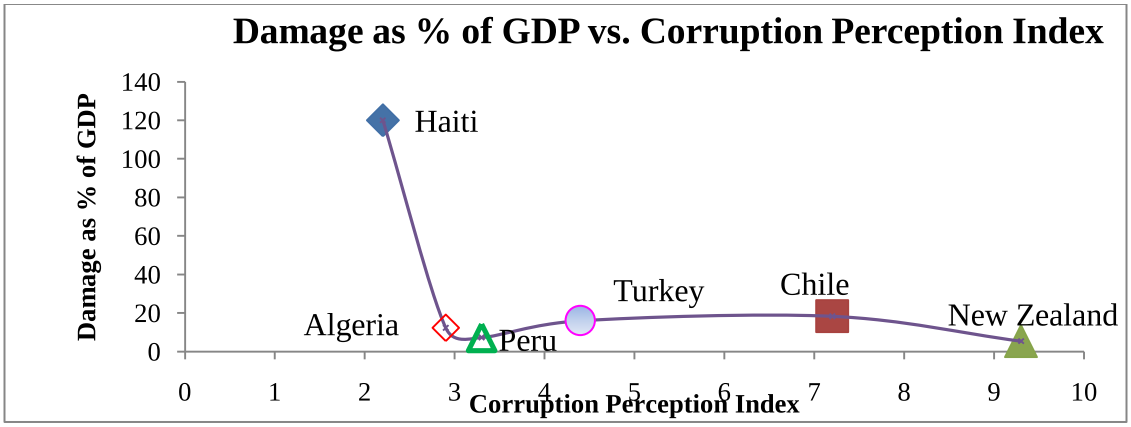


Figure 6-7. Damage as percentage of GDP versus Corruption Perception Index with addition data.

6.3 Population impact

One primary factor affecting economic growth in Haiti is the population density, shown in Figure 6-8 below. Haiti's population density was 356 people per square kilometer in the year 2010. This adds another factor for risk, beside the natural hazards that Haiti is dealing with is the daily health risk such as limited access to clean drinking water, lack of sanitation and insufficient supplies of food. The exposure to risk here also stands out with another measurement indicator, the overall rise in population. Consequences of this characteristic include land erosion, pollution and technological hazards, and forest degradation which increase vulnerability to natural hazard risk (Lundahl, 1991).

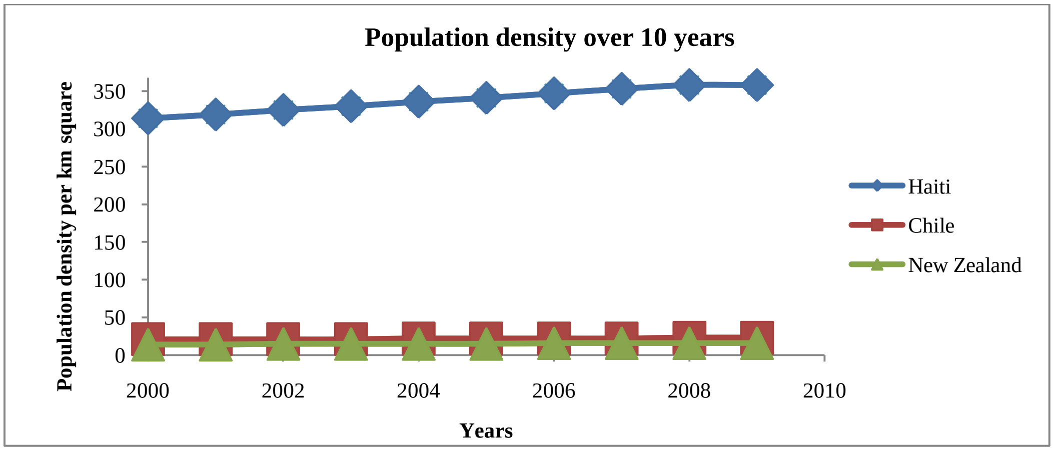


Figure 6-8. Population density over a 10 year period.

Shown also in the figure are the trends for Chile and New Zealand. In contrast to Haiti, the other two countries actually face a different type of risk: since their population is aging, the population growth of these two countries has stopped increasing at a rapid pace. The scale of the chart does not allow one to see the growth of the population in these two countries, but rather, it shows how much different the population density of Chile and New Zealand are versus Haiti.

The intention here is to illustrate the combined effect of population density and the economy together. As mentioned earlier, the vulnerability from these factors is not only impacting the economy itself, but also exposing it to multiple types of risk, primarily caused by human vulnerabilities. Population density, however, can be one of the contributors to the country's economy due to the fact that labor source is a significant component that can assist the country itself. One example is China, where the labor source is the most supportive role to its economy currently (Economist, 2010). A strict requirement for development in a country with such high population density is that that country has to organize its people in such a system with proper plans and basic needs. Port-au-Prince, Haiti and Santiago, Chile have large population densities, with over 12% and 28% of the entire country's population, respectively. Now the challenge for Haiti is how to decentralize the people as well as jobs and basic needs so that people will not group together in one place (Times, 2010). Prior to the earthquake, much of the economic activity in Haiti took place in Port-au-Prince and contributed up to 85% of government revenue (EERI, 2010). Following the decentralization plan will be a need for regulation of the country as a whole, so that the economy can evenly improve all over the country, in lieu of having 85% focused only in the Port-au-Prince area. Decentralization is still one of the challenges for Haiti, along with many other aspects. Decentralization and creating jobs can be considered the first steps for Haiti to guide development in the whole country more systematically.

6.4Loss of Life and Resistance Capacity

When the catastrophic earthquake occurred in Haiti, it appeared to lead the community to instability, shock, and reduced resilience capacity. The lives lost in the event serve as a metric of the performance of the country's hazard resistance capacity. Haiti touched the whole world after the 2010 earthquake, when there were over 300,000 lives lost. As mentioned previously, the loss of lives also signifies a great loss of skill, knowledge and capability of the entire society. The impacts from economy do not only apply to resilience capacity of a community but also onto the resistance capacity of that community as well. The relationship between loss of lives and economy in GDP is graphed in Figure 6-9. This trend is actually similar to the previous chart. The curve decays dramatically as the GDP of a country increases. In Figure 6-9a, the ratio of loss of life to the population of the whole country was used. One question is: would it be reasonable to use the number of victims compared to the population of the whole country to graph versus the economy? If the number of victims were compared in a larger country with commensurately larger population, for instance China, then the definition of risk exposure would be dimished because of the large total population. To avoid this, the risk was also defined as a percentage that reflected the impacted population. The value graphed in Figure 6-9b is the ratio of loss of lives for the exposed population within the area of significant earthquake shaking.

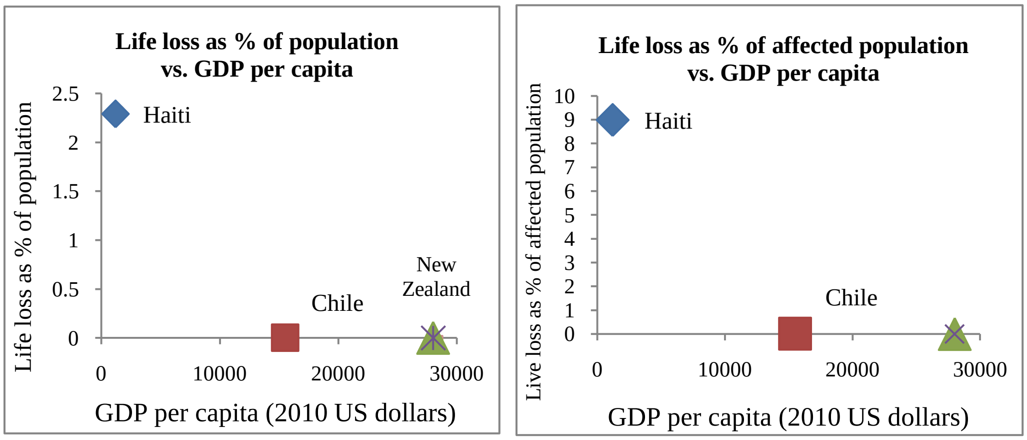


Figure 6-9. a. Life loss as % of population vs. GDP per capita. b. Life loss as % of affected population vs. GDP per capita.

The life loss curve in Figure 6-10 represented a smoother relationship. The relationship here points out one fact that the vulnerability of a community (Haiti, for instance) is relatively larger as the economy of the country itself is weaker. Yet, there is also an inconsistent perspective view of this relationship; it is the dependence on the particular area in each country. Nevertheless, there appears to be a stronger relationship between the state of economy and human vulnerability toward risk than the dollar value of damage experienced.

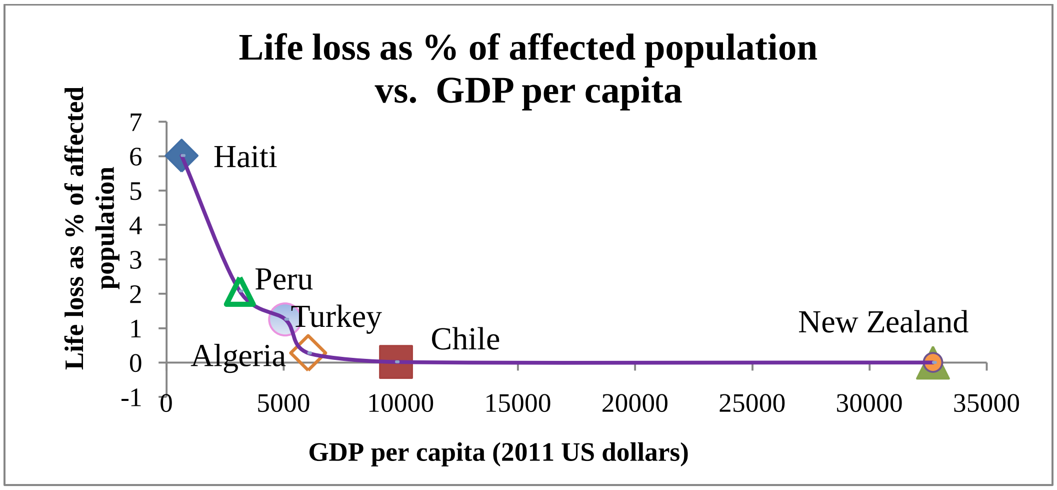


Figure 6-10. Relationship of causalities as a percentage of affected population and GDP per capita

6.5 Economic History and Resilience Capacity (a year after the earthquake)

A major obstacle in implementing a plan to reduce the exposure toward risks is that it requires observation of a country's activity over time. Understanding resilience capacity of a country is part of the risk exposure reduction plan. One of the simplest observations is by looking at the country's economy over a period of time. A common definition for resilience in society is a measure of the time needed to enable the economy to recover to pre-event levels. Again, given the development represented by the measurement of the GDP, the resilience capacity of the three countries is investigated. The resilience concept is based on the performance of the whole union of society, politics, and economy. All three earthquakes happened in 2010, and a full year has passed for Chile and Haiti's cases, but for New Zealand less than six months have passed at the time of this study. Accordingly, the economic statistics of 2010 have been recorded, and again play an important role in deciding the resiliency capacity of the society as a whole. Shown in Figures 6-11a, 6-11b, and 6-11c are the trends of three countries' economies.

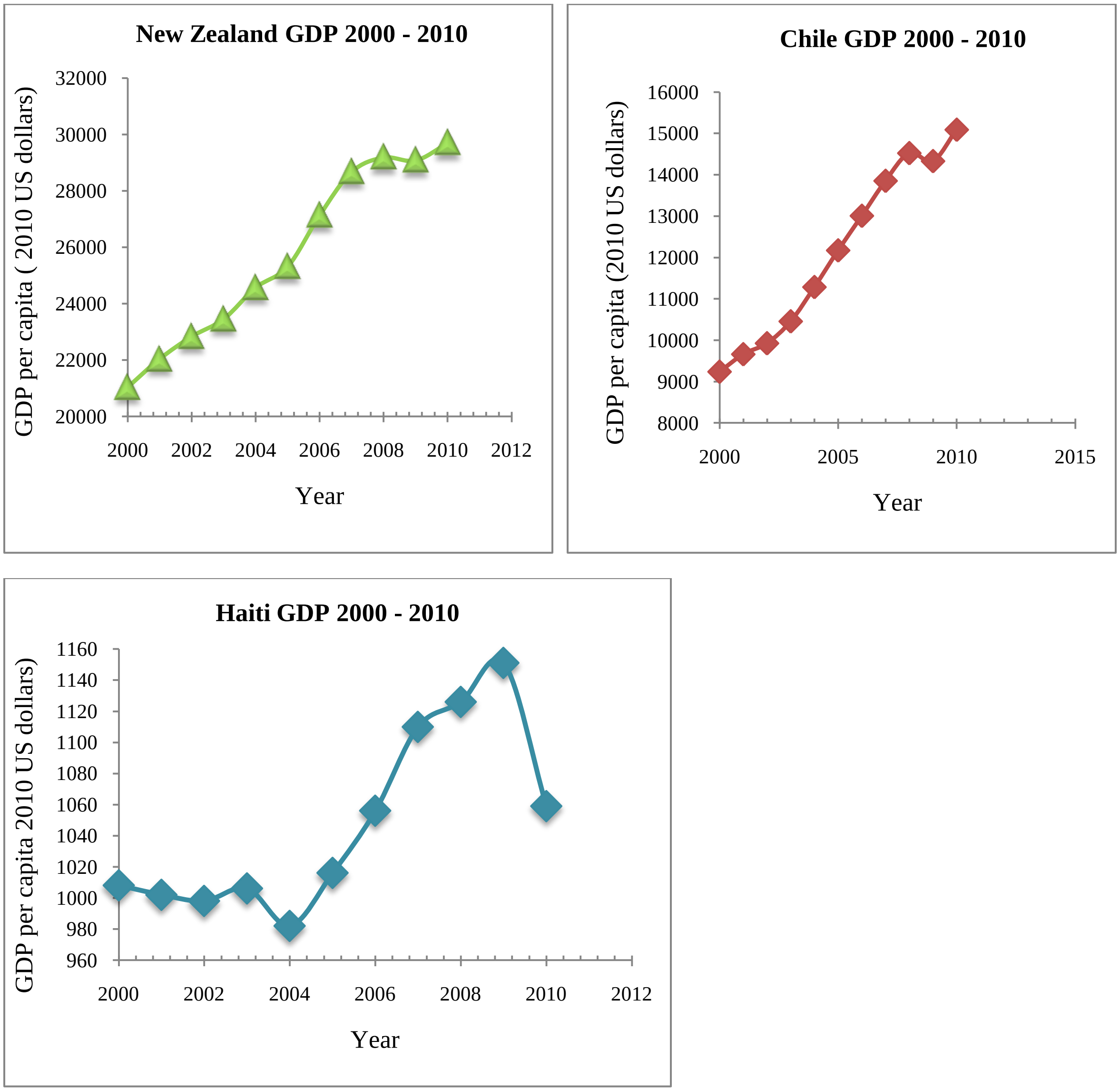


Figure 6-11. a. New Zealand's GDP. b. Chile's GDP. c. Haiti's GDP

Incident points are the drop down portions in the year 2010, the time after the earthquake. The GDP dropped away from the slope of its trend from the year 2000 till the end of the year 2009. An encouraging part in Figures 6-11a and 6-11b is that the GDP of New Zealand and

Chile in 2010 were trending upward and increased above pre-earthquake levels. On the other hand, Haiti's economy has experienced a continual downward period (see Figure 6-11c).

Resilience to natural hazards is the ability of a community to adapt to hazardous stresses (Pelling, 2010). Resilience also appears as the degree of production of planned preparation undertaken in the light of potential and spontaneous response to hazard. So, in order to indicate a resilience capacity, the resilience has to be a measurement factor. In this case, the ability of a country to develop its economy after a hazardous disturbance is used as that factor. Taking this concept into consideration, the resilience capacity of New Zealand and Chile showed positive increasing slopes on the graphs as seen on Figure 6-11a and 6-11b. A commonly asked question is: what are the details of the resilience capacity indicated by these positive slopes shown on the graphs that allowed Chile and New Zealand to overcome the impacts caused by the earthquakes?

Clearly, Haiti's economy actually shrank 8 percent by the damage done in Port-au-Prince (CIA, 2011), which is likely less than what one could imagine, despite much help, and debts voided by the World Bank. In terms of the concept of resilience, the path of the last two years in Haiti reduced as a slope of -92, shown in Figure 6-12c. Or, one could argue based on reconnaissance team reports that according to the reduction amount, Haiti's economy indeed dropped vertically and has not increased for the past year, as illustrated as a dashed line. So the risk is actually larger in the future since Haiti will need a considerable amount of time to get its economy back to the level of the past trend from the year 2000 to 2009. Resilience capacity in Haiti will need more time to indicate whether the country's economic activity can return to its previous trajectory.

In contrast to Haiti, the economy in Chile prior to the earthquake experienced a deficit from the years 2008 till 2009, shown in Figure 6-11b. During this period, the country's investments dropped about 7 billion dollars by the end of 2009. Chile's independent wealth fund, amounting to more than $20 billion, was kept mostly outside of the country and separated from the central Bank reserve. During this period, the Chilean government conducted a rule-based countercyclical fiscal policy. The rule accumulated surpluses in sovereign wealth funds, and allowed deficit spending only during periods of low copper prices and growth (CIA, 2010). At the beginning of the year 2009, Chile's economy started to show signs of a rebound. Despite the impact of one of the largest earthquakes in its history, Chile's economy had increased by 5.3 percent by the year 2010. In the concept of resilience capacity, this positive increase plays a significant role in the capability of the whole community. In fact, this slope represents the ability to move the country away from environmental risks.

Unlike Haiti, New Zealand controlled the shock quite well. New Zealand recognized the principal of controlling its resilience by using an insurance mechanism. At the time of the 2010 earthquake occurrence, more than 70 percent of the New Zealand population had insurance that covered environmental risks. This was the key tool in New Zealand that helped the country. Insurance represented an action that reflected the public educational background on preparation and planning to reduce the human vulnerability toward risks. One important aspect in New Zealand was the behavior of structures during numerous aftershocks. The behavior during aftershocks of structures that have experienced damage in a major earthquake is a topic for future research, even in America. As mentioned previously, New Zealand is subject to many earthquakes and aftershocks caused by the seismicity geography. New Zealand in general, and Christchurch in particular, must face the decision whether or not to spend a great amount of money in constructing "earthquake proof" buildings so that earthquakes cannot have a significant impact on them. From an engineering and economic point of view, this is an irony about building codes, in which costs to "earthquake proof" structures may never be utilized. Using the damage to pre-1968s buildings in New Zealand as an example, the need of replacing these aging facility or even retrofitting often times gets pushed aside by more urgent issues—after all, money is in short supply. However, it is important to bring all buildings—new and old—up to date with the law because earthquakes cannot be predicted ahead of time and it is too late to think about retrofitting a building after such an event. In contrast with Chile, the economy in New Zealand did not increase as much after the earthquake as that of Chile's. However, the economy in New Zealand did not decrease as much as that of Haiti's as a result of the earthquake. The level of stability of each country's economy is reflected by its ability to resist being affected by disasters as well as its ability to recover from them. It is somewhat interesting to realize that the slopes before and after the shocks are similar or very close to each other in the case of Chile. Examining a snapshot from the last five years from 2005 to 2010, shown in Figure 6-12 a, b, and c respectively, is very interesting, and more study of the effect of the state of the economy on resilience is warranted.

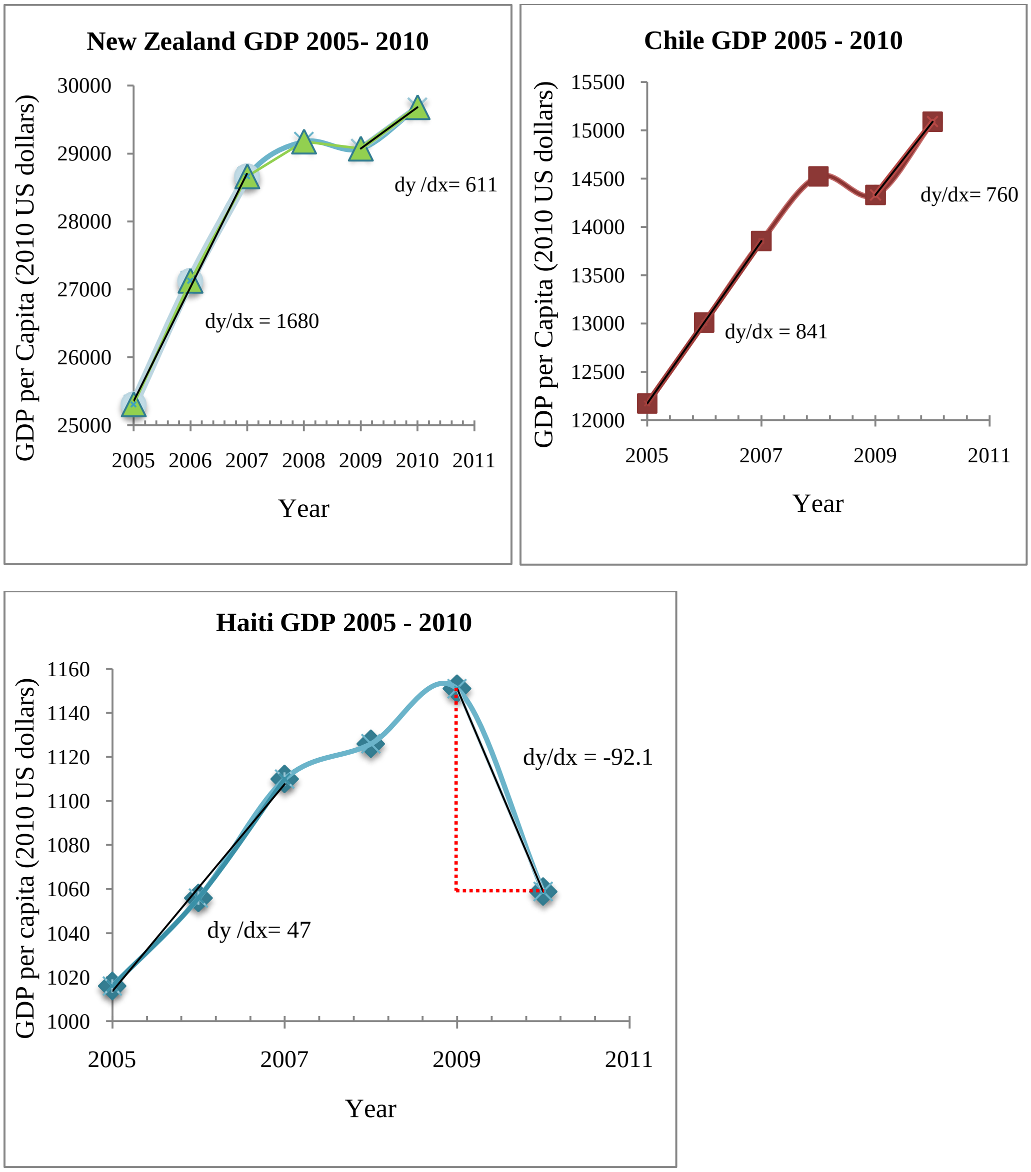


Figure 6-12. a. New Zealand's GDP . b. Chile's GDP. c. Haiti's GDP

Observation from the trend of the three graphs above shows the aspects of the economy that can protect the people of Chile and New Zealand. Having a developed economy perhaps also helps the community to be able to establish and enforce proper building codes. The result of having a developed economy is so obvious that one can even observe that it enhances the education by a large scale, for instance New Zealand’s community aware the help from having insurance. Sustainability in Haiti has been a challenge over the years, it is important for Haiti’s government to swiftly realize what issues are the top priorities for them to reconstruct their systems. This will enhance development within the country's economy, and the establishment of a seismic standard can be a subsequent task.

6.6 Value of Infrastructure

Damage during the earthquakes has been expressed up to this point as a fraction of the economy of the country, which is assumed to reflect the development of that country in terms of infrastructure. The premise is that the larger the amount of damage as a fraction of GDP, the worse preparation the country had. Similar to the number of loss of lives, however, an alternative approach is to consider the absolute value of the damage. For Chile the amount of damage during the earthquake was about 31 billion US dollars, which is the highest number compared to the other countries. The reason is not from poor preparation of the country prior to the natural hazard; instead it is in terms of the high value of the existing infrastructure. As shown in Figure 6-13 below, the three countries' damages scatter instead of correlating in a certain order.

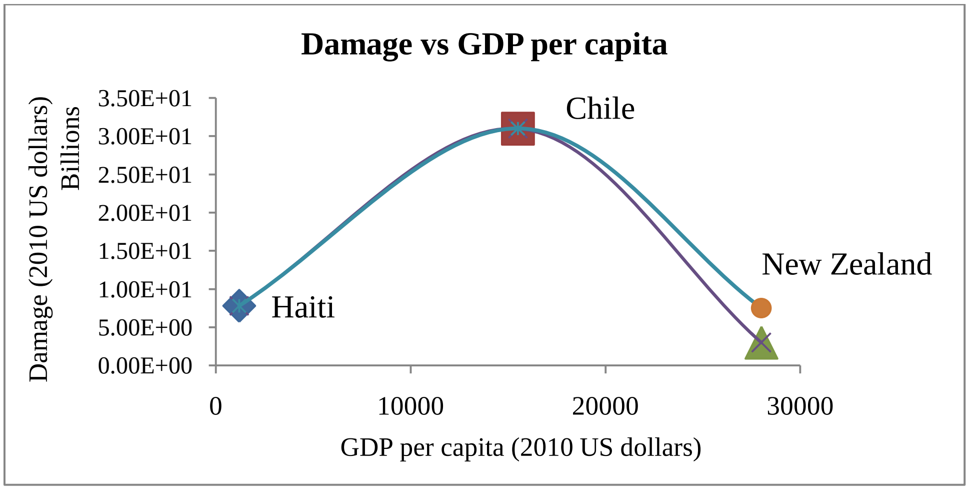


Figure 6-13. Damage as a total amount versus GDP per capita

The earthquake caused the highest amount of damage in Chile; this amount of damage included the values of roads, bridges, ports, and houses. The Chilean government will spend an additional $1 billion on emergency relief measures. Public sector damage (e.g., hospitals and schools) will amount to $9 billion (US Department of State, 2011). The amount of damage included 33 percent just from the damage to schools and hospitals. So the percentage of damage from roads, bridges, houses, permanent losses such as economic losses (loss of production, reduction in turnover, loss of employment and salaries, increased costs of production, etc.) was 67 percent.

Unlike Chile, damage in Haiti was mostly from the cost of houses, explicitly, most damage and losses were experienced by the private sector. The amount of damage for the private sector was $5.5 billion, or equivalent to of 70 percent of the total damage. The public sector impact was $2.4 billion, or 30 percent of the total. The value of destroyed physical assets--including housing units, schools, hospitals, buildings, roads and bridges, ports, and airports--was estimated at $4.302 billion, which is 55 percent of the total of all effects of the disaster. In addition, economic losses (which mainly occurred in Port-au-Prince) reached $3.561 billion, or 45 percent of the total. Within the amount of $4.302 billion, housing was the sector most affected by the earthquake, with damages estimated around $2.3 billion. Loss from trade due to damages was $639 million, or 8 percent of the total. Losses from transport and government buildings were $595 million each, and the loss of roads equivalents to 8 percent of the total damage (US Department of State, 2011). Clearly, the amount of damage from houses is considerable, which places a concern in the willingness to pay within the society such as through an insurance mechanism, the concept of which appeared to be nearly non-existent at the time of the state of emergency.

To stay consistent with previous parts, the total damage once again is plotted in terms of the value of structures only. Here, in Figure 6-14, the amount of damage in Haiti, Peru, and Algeria implies the possible destruction of the earthquake to the available infrastructure, in Turkey and Chile, the dollar value of damage was much higher since there were more structures built. New Zealand again stayed out of this range since the economy of the country is much more developed than the other four countries and its building code was more enhanced.

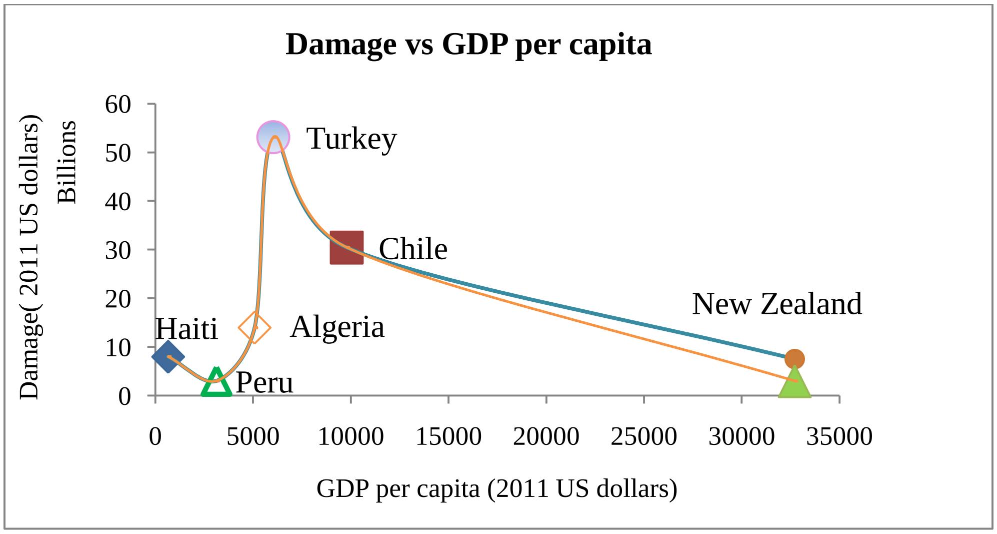


Figure 6-14. Damage as total amount versus GDP per capita (2011 US dollars).

6.7 Summary

It is important to emphasize that among all the challenges faced by the Haitian people, risk management is the most complex. To be able to manage risk, Haiti should clearly be aware of the needs for managing its risk, including short term needs and long term needs. Using the rubble removal in Haiti as an example, based on the estimate by DesRoches, the time needed to clear the rubble is the range of 3 to 5 years (DesRoches, 2010). At the time of writing this paper, it is a year from the date of the disaster, and Haiti has only cleared 20 percent of the rubble (Rodgers, 2011). This percentage of removal seems trivial, but the challenge Haiti is faced with is the high possibility of having another disturbance—an earthquake or a hurricane—that would cause the country to reach a "paralysis" condition of rubble removal such as if this condition had happened during the middle of the year 2010 (Rodgers, 2011). So to get to the trajectory of the activity before the earthquake or to bring up the resilience, Haiti's revival (not only in particularly rubble removal) still needs time and extra help from countries around the world.

Since natural hazards will always exist as a threat against the country, Haiti needs a plan to rebuild, reorganize, and prepare their country for the disaster. Based on the above analysis, rehabilitation of Haiti's people and repairing the country's critical infrastructure is their first priority. Rehabilitation of the people requires an organized system and cannot be considered only the temporary solution. If Haiti can organize the small community system, then such activity can do the same to the larger scale of society. Once the people are adequately secured, the country can then concentrate their resources in disaster mitigation. However, for this to occur, the Haitians are required to combine their effort to help revitalize their country for their own sake.

Shown in the above analysis, there is a relationship between damage and economy, between political system and damage, and between population and damage. If vulnerability is an outcome of the combination of factors that include economic, societal, and political systems, then what type of factors are engaged in the potential for risk reduction? In the next chapter, this question will be answered with a summary of high points and supporting illustrations.

Chapter 7

Conclusion

7.1 Remarks

While it is useful to have a picture of the susceptibilities of Haiti by looking at its social and political histories, it is imperative to have a dialogue between the different parties involved in the society to reduce risks and plan for future disasters. Collaboration between the analysis and reconstruction of Haiti go hand in hand. A reminder of the impact of a natural hazard—an earthquake in this case—is made by Tom Paulay (2011) who said that "seismic design is a solemn responsibility." Perhaps the meaning of responsibility here is that every party—the scientists, the engineers, and the government—have a duty to help their country both prepare for and recover from a disaster. Thus, it is time for every sector of the community to put together the needed efforts to push their responsibility toward revival of the country.

A summary of the concern of this thesis is well represented by Figure 7-1. This figure shows the measure of activity (for example, GDP per person) within a community over time. The measure of activity of the society prior to the earthquake is assumed to be approximated as a straight line, and the occurrence of the disaster event causes the incidence point. The trajectories of recovery depend upon the resilience of the society. At the occurrence of the disaster, the influence of society, politics and the economy have a profound effect on the magnitude of the damage suffered in the community. The drop in activity will certainly be influenced by the robustness of the community’s built infrastructure, a direct reflection of the effective incorporation of design for low probability, high consequence hazards in the building code, and the enforcement of that code. Of equal significance, the participation between engineers and society during the recovery phase determines the time and trajectory for the communities to reach a point of recovery.

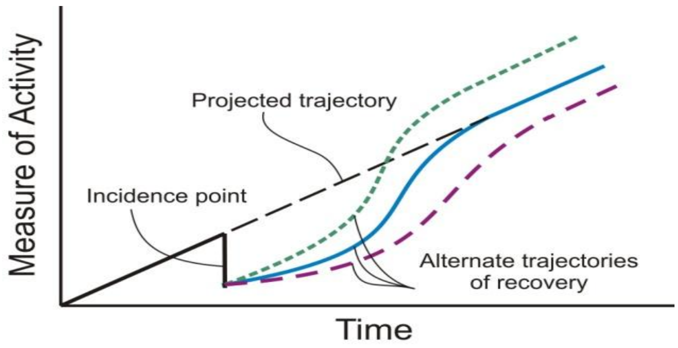


Figure 7-1. Community activity and recovery over time (Corotis, 2011)

The integrated difference between the projected trajectory and the actual recovery trajectory is a convenient measure of the lack of resilience of a society. This area is a combination of numerous factors, which are dependent upon the development level of the country and the risk level acceptance within the country itself. In particular, they are:

1. Stability of democracy.
    - The stability of democracy depends on the involvement of society and politics with the development of a community. It is an important idea that reflects the strength of the government, and this was almost completely absent in Haiti’s system.
2. Health of social fairness reflected in measurement of corruption.
    - As mentioned in Chapter 5, the measurement of corruption reflects how a country which exhibits an abuse of entrusted power for private gain or encompasses corrupt practices in both the public and private sectors negatively affects the growth and progression of that country. There is a close relationship of this

measurement to the economy of a country. The change in system of governance can provide opportunity to enhance the adaptive potential of a community to improve the economy.

3. Stability of population along with land usage and forest preservation.
    - Rapid increase in population and frequently dealing with natural hazards such as hurricanes and earthquakes increase the human susceptibility to the hazard. Consequences of this over-rise in population characteristic led to land erosion, pollution, technological hazards, and forest degradation which increase vulnerability to natural hazard risk (Lundahl, 1991). The evidence of this aspect is that as of 2008, Haiti has destroyed almost all of its forests, in contrast to its neighbor on the Island, the Dominican Republic.
4. Even geographical distribution of employment.
    - If Port-au-Prince was not so congested and Haiti did not rely almost completely on Port-au-Prince for its economic activity, then the economic impact of the earthquake would be smaller. As a result, the decentralization proposal for reconstruction, although a challenge, could help reduce future economic risk from natural hazards.
5. Establishment of building standards, especially for seismic areas, along with enforcement.
    - One of the obvious reasons for Haiti's devastating damage was the absence of building standard. Yet, Haiti is not the only country that suffers from the lack of a building standard and enforcement, Viet-Nam is one of just many examples.

Even though Viet-Nam does not belong to a seismic area, establishment of building standards for similar countries including Haiti itself is a must.

6. Improvement of material qualifications and construction specifications.
    - There is a close connection between material qualifications, construction specifications, and structural response during the earthquake. This relationship needs an establishment of enforcement.
7. Progression of public education, including in terms of insurance mechanisms.
    - Awareness of the existence of risk and its impacts to a community is difficult to extend; to be prepared for its consequent occurrence is the most challenging aspect of risk mitigation. Public education of the risks of the hazard is currently underdeveloped in Haiti. In addition, 30 % of New Zealand's population does not have insurance to cover disasters like earthquakes (RMS, 2010). A lack of understanding of the probability of risks to occur at any given time is severe. For instance, sociological studies have demonstrated that people often think that the difference from 0% to 1% of probability is greater than the difference from 35% to 36 % (Patt and Zekhauser, 2002), it is clear that knowledge in probability is needed, particularly in an area that is subjected to frequent occurrences events from natural hazards. This concept should not only apply to Haiti itself, but also to Chile, and other countries around the world.
8. Application of a simple method to be used in a developing country such as a dampened base isolator for structures (an adapted idea from Professor Sivaselvan, 2011)
    - While base isolator applications have been a topic for research, it appears that this type of structural foundation is complicated to implicate and is relatively

expensive to install in a developing country. It would therefore be more efficient to have a simple design of a dampened base isolator structure for a developing country to use.

As all these factors are involved in the development of a community, the result from any one deficiency is considerable, as seen in the devastation of Haiti after the earthquake. With the memory of the earthquake still fresh in people's minds, this is the time when all these factors need to be improved. As seen in the previous chapters, the relationship between the economy, society, and the government directly affects the resilience capacity within the community. Since both the quantity and quality of economic resources are very important, the risk level that a developed economy accepts is reflected in the economic stage of development of the country itself. But if the memory of the earthquake fades from people's minds, the country might never recover from the disaster—after all, what would be the motivation to improve on these factors if everyone forgot what has happened in the past?

a. *Future research topic suggestion*

There are many other factors that this paper did not cover because of time constraints and information-dependent conditions. For instance, the case study using structural software to model the Chancery Former US Embassy and performing a seismic analysis on the model was incomplete because of the lack of precise behavior of the masonry infill structures that were very common when the building was built in the 1950s. In addition, the seismic hazard curve from the time the structure was built is very different from the one from the 2010 earthquake; therefore, it is very challenging to perform a seismic analysis on this particular building. Despite this insufficient information, demonstration of a building that was designed based on a seismic standard was able to be presented; thus, its behavior during the earthquake was able to be captured and contrasted. The results from natural hazards are unpredictable and completely dependent on the level of risk a community accepts. Therefore, to quantify this result in term of structural behavior of certain structures, it is necessary to have a precise design hazard curve from accurate ground motion data. The same argument can be made for the resilience capacity analyzed in chapter 6.

It is inadequate to conclude that the result from the earthquake in Haiti was due solely to the country's poor economy; thus, further analysis should be done in order to complete the picture of risk management needs and reductions of human susceptibilities to natural hazards, including hurricanes. In addition, application of methods to represent damage of natural hazards in a better way which can quantify the loss of community's value, destruction of towns, or impact of economic loss in particular areas is necessary. While calculation is based on the specific data in references, it is not ideal to point out solely the relationship of vulnerability and stage of economy since each area or community within a country contributes differently to the country's economy. A normalized contribution of each damaged area is needed, as well as the losses within a community and impact of large scale dislocation should be included as well.

A recommended focus could be the enforcement system in the country's implementation of codes, the code comparison between Chile and the United States, particularly in masonry design, or the impacts of natural hazard frequency of occurrence on structural behavior. As mentioned in Chapter 6, the impact of natural hazard frequency is somber: for instance, at the time of finishing this thesis, an earthquake with Mw magnitude 6.3 occurred in New Zealand on February 24, 201, causing 160 deaths according to current estimates by the BBC (as of 3-2-11). A common question is why something like that could happen while the occurrence of a magnitude 7.1 in the same area caused no deaths. Part of the answer is that the second earthquake had a different epicenter location and depth, characteristics not reflected in a single number such as the magnitude, which is commonly used to quantify the impacts. Another part of the answer is that retrofitting often needs time to make upgrades or changes. It will be best to update buildings whether or not they collapsed as a result of the design spectrum. Therefore, it is necessary to determine which design response spectrum was used when these buildings were constructed.

b. Close up

In conclusion, the paper presents an investigation on the underlying relationship between the implicit level of risk accepted for natural hazard vulnerability, and the level of economic, social and political development of the country. In addition, a list of the differences among the three events, as well as commentary on some of the social aspects that led to the conditions at the time of the earthquakes, has been made. With the variables considered such as the magnitude of earthquake, depth of the hypocenter, local geological conditions, demographics of the population, population at risk in the area of the earthquake, and performance of structures in the affected areas, one can form a good estimate of how a particular earthquake would affect the community. Vulnerability information is also related to the seismic provisions of the building codes, and the atmosphere of code enforcement. As damage has been and is continuing to be investigated by several countries concerning the loss of lives, injury, property damage, and how well various structures have performed in the country, more data will become available so that more research can be done on this subject. In addition, there should be studies that would help lead Haiti to depend more on itself after a disaster, rather than to desperately and constantly rely on aid from foreign countries (O’Connor, 2011). Finally, after such a disaster, the people of

Haiti deserve better conditions than those they are experiencing currently, and it is both an obligation and opportunity of the foreign community to help them reach that goal.

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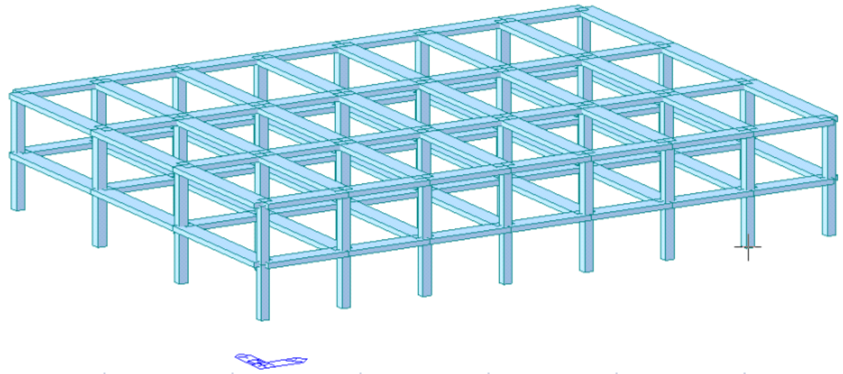
Appendix 1. Building layout

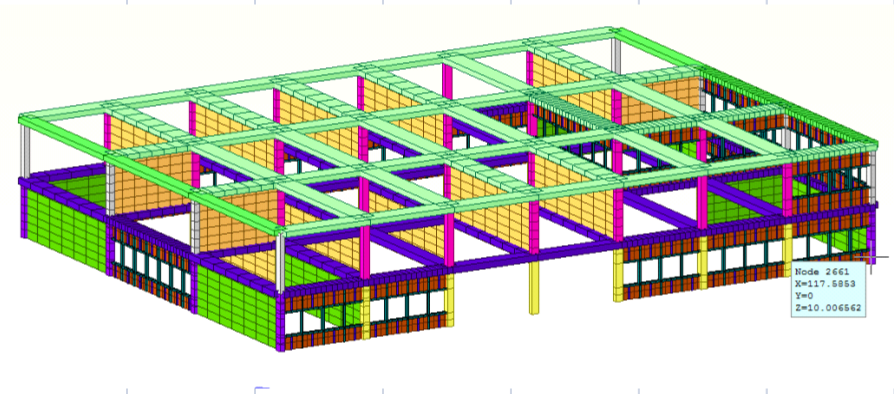
Table1. Building information.

Building Informatior	Value	Units	Notes
Building Length	118	ft	N-S
Building Width	88.2	ft	E-W
Building Height	21	ft	total
Area	10408	ft^2	per floor

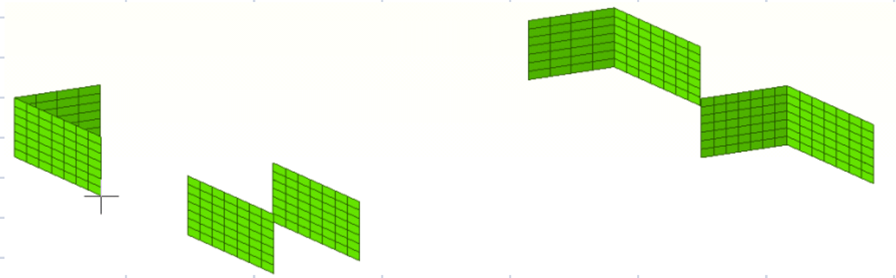
Figure1. Building Layout



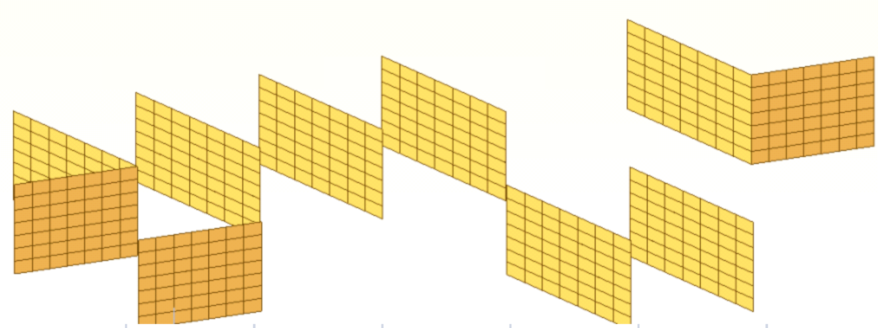
Orignal building with concrete frame, walls, and steel panels



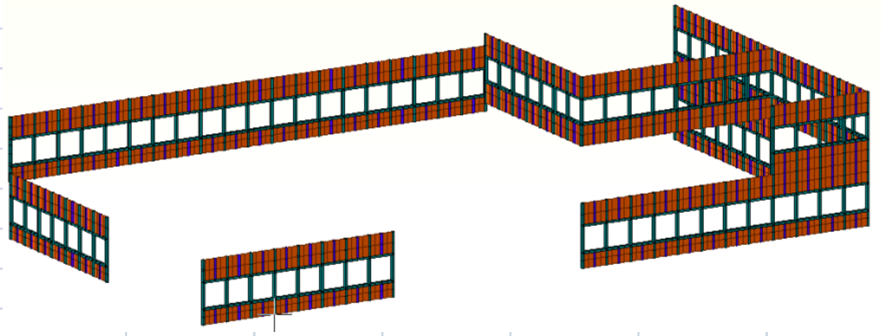
Stone



Concrete masonry unit

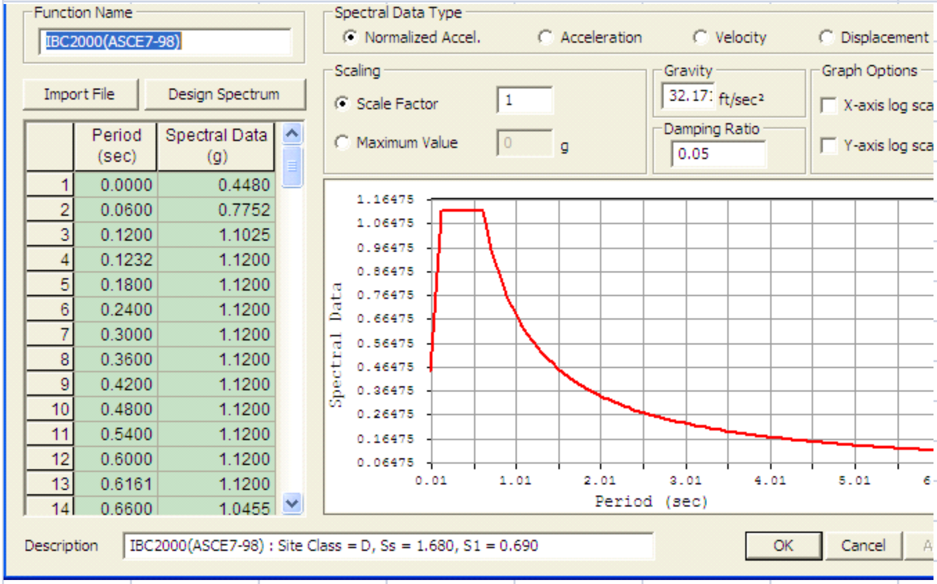


Steel panels



Appendix 2. Design spectrum

Design Spectrum from the Model by Modal Response Spectra Analysis



Function Name: IBC2000(ASCE7-98)

Spectral Data Type: ● Normalized Accel. ○ Acceleration ○ Velocity ○ Displacement

Scaling: ● Scale Factor 1 ○ Maximum Value 0 g

Gravity: 32.17: ft/sec²

Damping Ratio: 0.05

Graph Options: ☐ X-axis log sca ☐ Y-axis log sca

	Period (sec)	Spectral Data (g)
1	0.0000	0.4480
2	0.0600	0.7752
3	0.1200	1.1025
4	0.1232	1.1200
5	0.1800	1.1200
6	0.2400	1.1200
7	0.3000	1.1200
8	0.3600	1.1200
9	0.4200	1.1200
10	0.4800	1.1200
11	0.5400	1.1200
12	0.6000	1.1200
13	0.6161	1.1200
14	0.6600	1.0455

Description: IBC2000(ASCE7-98) : Site Class = D, Ss = 1.680, S1 = 0.690

Appendix 3. Period check, shear check.

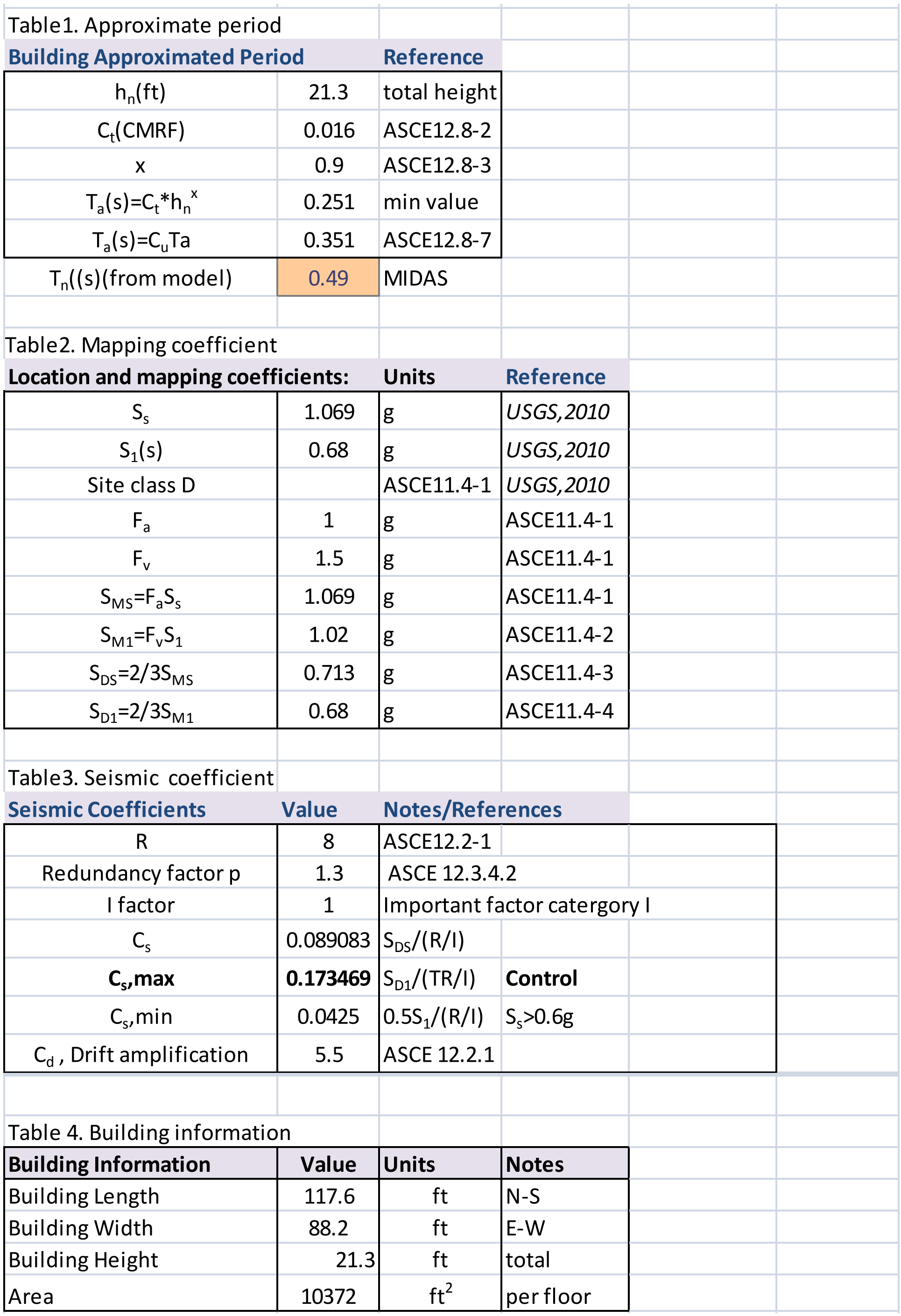


Table1. Approximate period

Building Approximated Period		Reference
h_n(ft)	21.3	total height
C_t(CMRF)	0.016	ASCE12.8-2
x	0.9	ASCE12.8-3
$T_a(s)=C_t*h_n^x$	0.251	min value
$T_a(s)=C_uTa$	0.351	ASCE12.8-7
T_n((s)(from model)	0.49	MIDAS

Table2. Mapping coefficient

Location and mapping coefficients:		Units	Reference
S_s	1.069	g	*USGS,2010*
S_1(s)	0.68	g	*USGS,2010*
Site class D		ASCE11.4-1	*USGS,2010*
F_a	1	g	ASCE11.4-1
F_v	1.5	g	ASCE11.4-1
$S_{MS}=F_aS_s$	1.069	g	ASCE11.4-1
$S_{M1}=F_vS_1$	1.02	g	ASCE11.4-2
S_{DS}=2/3S_{MS}	0.713	g	ASCE11.4-3
S_{D1}=2/3S_{M1}	0.68	g	ASCE11.4-4

Table3. Seismic coefficient

Seismic Coefficients	Value	Notes/References	
R	8	ASCE12.2-1	
Redundancy factor p	1.3	ASCE 12.3.4.2	
I factor	1	Important factor catergory I	
C_s	0.089083	S_{DS}/(R/I)	
C_s,max	**0.173469**	S_{D1}/(TR/I)	**Control**
C_s,min	0.0425	0.5S_1/(R/I)	S_s>0.6g
C_d , Drift amplification	5.5	ASCE 12.2.1	

Table 4. Building information

Building Information	Value	Units	Notes
Building Length	117.6	ft	N-S
Building Width	88.2	ft	E-W
Building Height	21.3	ft	total
Area	10372	ft^2	per floor

Table5. Distributed load assign for MIDAS model

Load	Value	Units
Roof Live Load	10	psf
Roof Dead Load	120	psf
Floor Live Load	25	psf
Floor Dead Load	150	psf

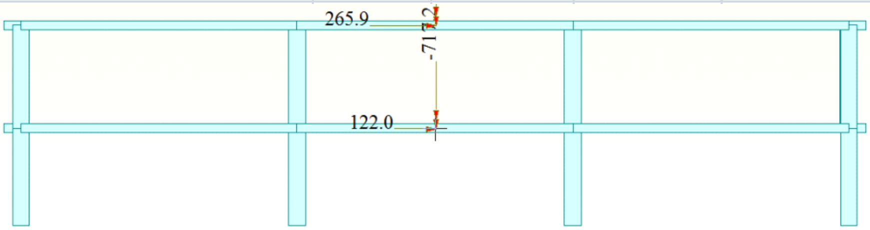
Table6. Base Shear calculation to compare with MIDAS in ELF method

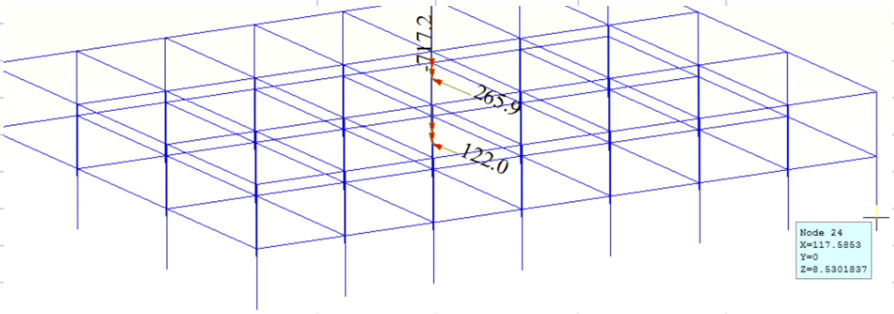
Base Shear Force:	Value	Units	Notes/References
W-roof	1141	kips	*beams carry selfweights*
W-floor	1037	kips	*beams carry selfweights*
W-total	2178	kips	ASCE 12.8.1
Vs,base	378	kips	Cs*W

Shear Force at each Floor			**Notes/References**	
k=	1		ASCE 12.812	
Vs=	**378**	kips--->	**BASE SHEAR**	
Floor	**h(ft)**	**W(kips)**	$W_xh_x^k$	C_{vx}
Roof	21.6	1141	24645	0.70
1st Floor	10.3	1037	10683	0.30
		346	0	0.00
		$\Sigma W_xh_x^k$	**35328**	1

Table7. Compare with MIDAS

Floor	F(kips)	1.05*F(kips)	Fmodel(kips	%Difference
Roof	264	277	266	4.0
1st Floor	114	120	122	-1.7
BASE SHEAR	378	397	388	2.3





Appendix 4. Load Pattern

Figure1. Dead load distribution (k/ft)

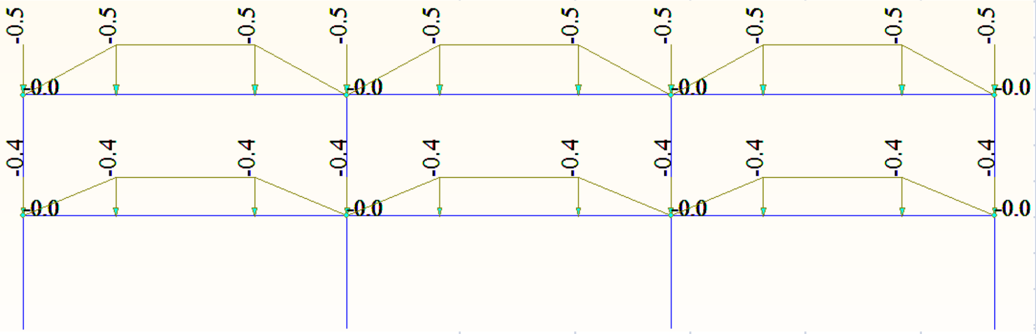


Figure2. Live load distribution(k/ft)

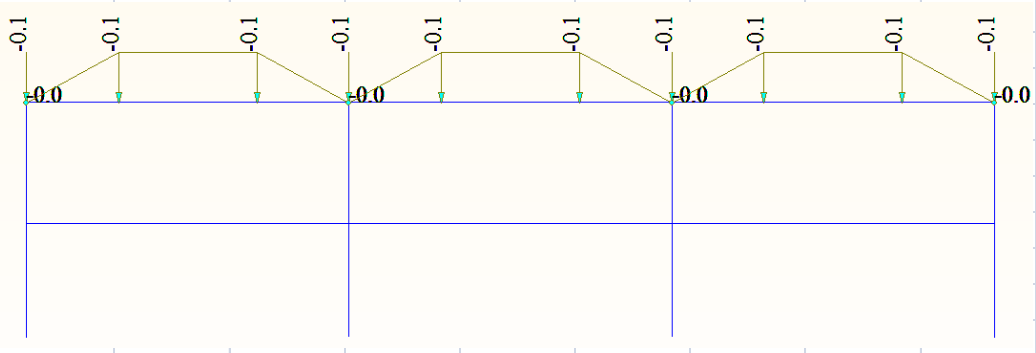


Figure3. Live load distribution(k/ft)

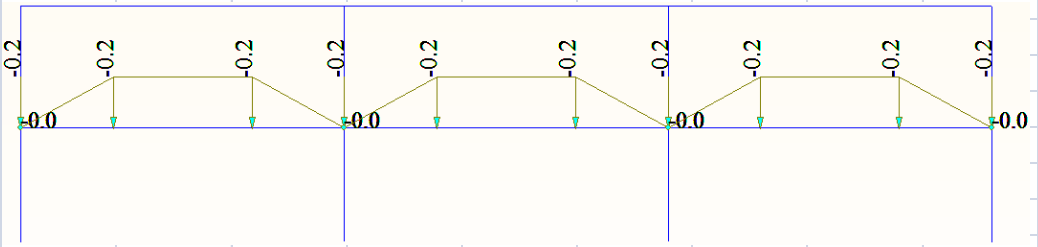


Table1. Distributed load assign for MIDAS model

Load	Value	Units	Distributed in Midas Units	
Roof Live Load	10	psf	1.00E-01	k/sf
Roof Dead Load	64	psf	6.35E-01	k/sf
Floor Live Load	25	psf	2.50E-01	k/sf
Floor Dead Load	50	psf	5.00E-01	k/sf

The weight of beams, columns, and wall elements is included separately in MIDAS included in the category "Self weight of structure."

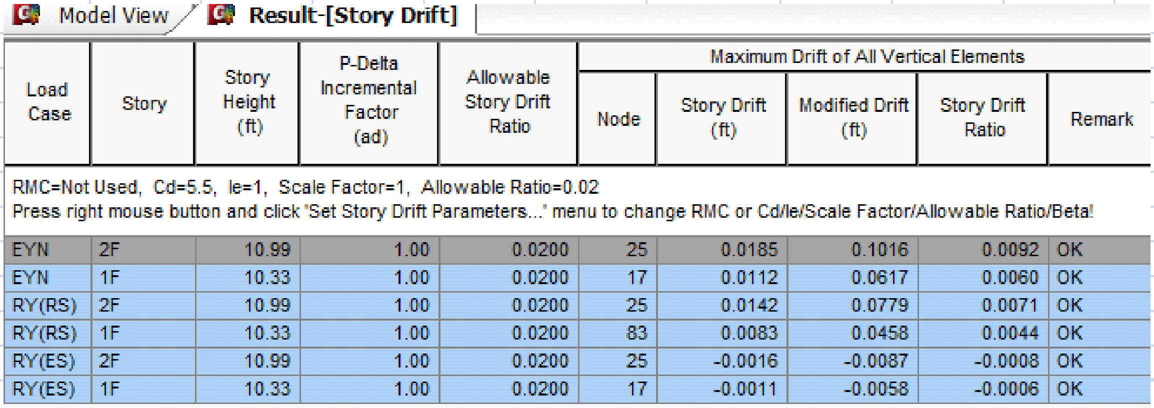
Appendix 5. Story drift check, Story stability check

Table1. Inter-story Drift Comparison

Story	Story Drift(in)			
	ELF $_{model}$	MRSA $_{mode}$	ratio(EFL)	ratio(MRSA)
Roof	0.278	0.169	0.012	0.007
Floor 1	0.172	0.100	0.007	0.004

Story Drift Check:
ASCE Table 12.12-1
Occupancy I
Allowable Drift:
$0.020h_{sx}$ in

Table 2. Story Drift from ELF and MRSA



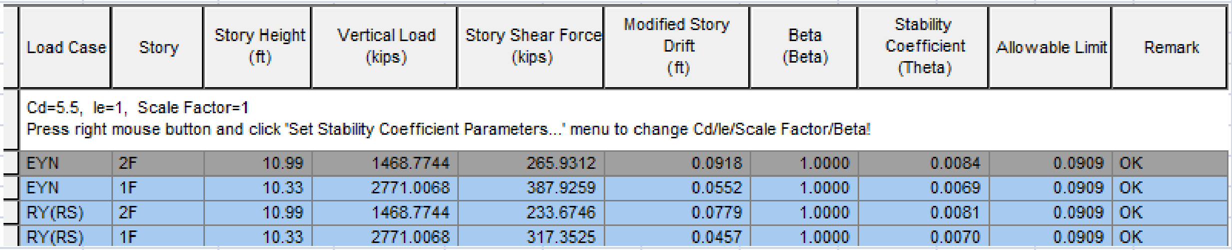
Load Case	Story	Story Height (ft)	P-Delta Incremental Factor (ad)	Allowable Story Drift Ratio	Maximum Drift of All Vertical Elements				
					Node	Story Drift (ft)	Modified Drift (ft)	Story Drift Ratio	Remark
RMC=Not Used, Cd=5.5, Ie=1, Scale Factor=1, Allowable Ratio=0.02 Press right mouse button and click 'Set Story Drift Parameters...' menu to change RMC or Cd/Ie/Scale Factor/Allowable Ratio/Beta!									
EYN	2F	10.99	1.00	0.0200	25	0.0185	0.1016	0.0092	OK
EYN	1F	10.33	1.00	0.0200	17	0.0112	0.0617	0.0060	OK
RY(RS)	2F	10.99	1.00	0.0200	25	0.0142	0.0779	0.0071	OK
RY(RS)	1F	10.33	1.00	0.0200	83	0.0083	0.0458	0.0044	OK
RY(ES)	2F	10.99	1.00	0.0200	25	-0.0016	-0.0087	-0.0008	OK
RY(ES)	1F	10.33	1.00	0.0200	17	-0.0011	-0.0058	-0.0006	OK

Story Stability Check:

$$\theta = \frac{P_x \Delta}{V_x h_{sx} C_d}$$

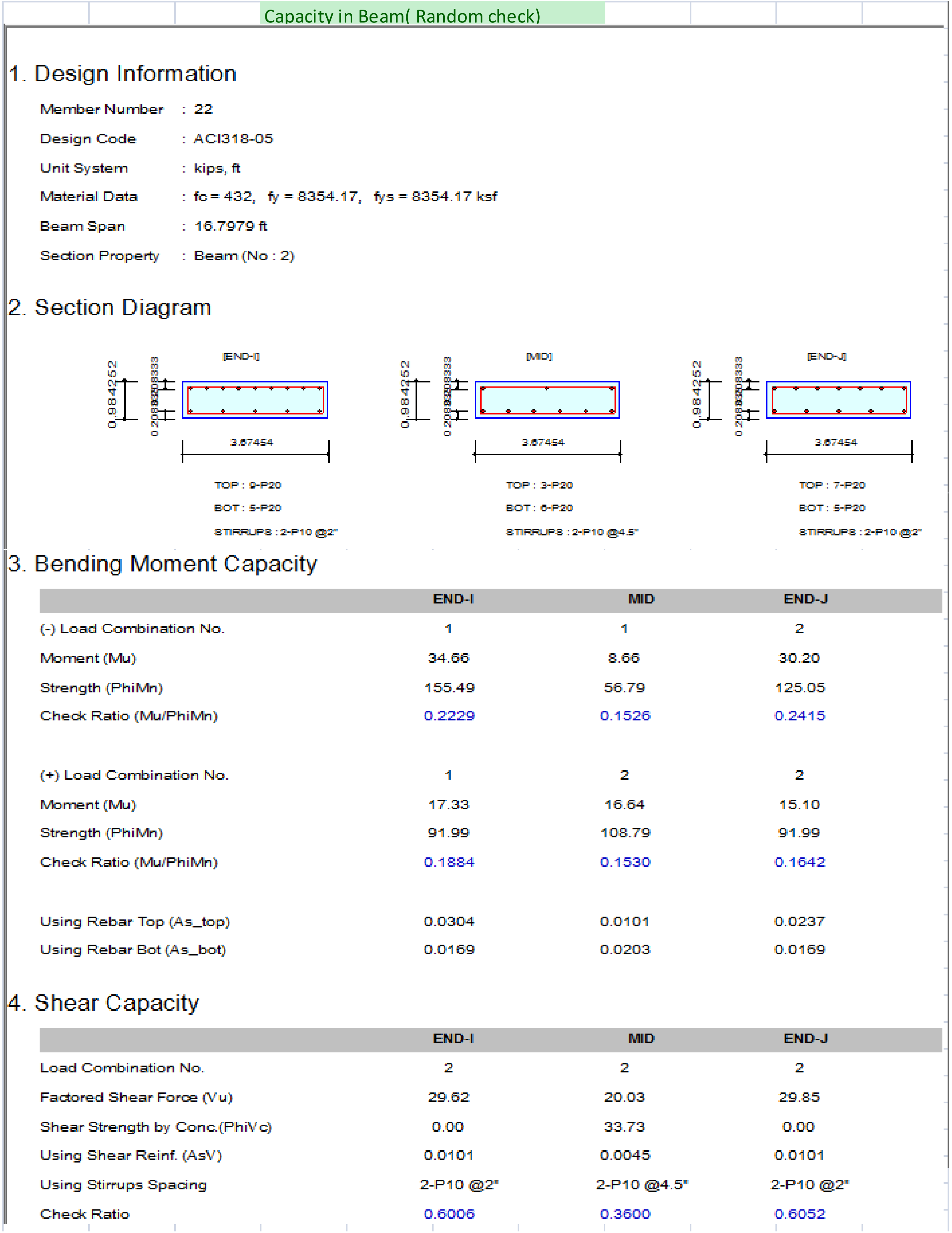
Px	total unfactored vertical design load at and above level x
Δ	story drift based on ΔS acting between levels x and x-1
Vx	design seismic shear force acting between levels x and x-1
hsx	story height below level x
θ	stability coefficient
Cd	deflection amplification factor

Table 3. Story Stability Coefficient Checking from ELF and MRSA



Load Case	Story	Story Height (ft)	Vertical Load (kips)	Story Shear Force (kips)	Modified Story Drift (ft)	Beta (Beta)	Stability Coefficient (Theta)	Allowable Limit	Remark
Cd=5.5, Ie=1, Scale Factor=1 Press right mouse button and click 'Set Stability Coefficient Parameters...' menu to change Cd/Ie/Scale Factor/Beta!									
EYN	2F	10.99	1468.7744	265.9312	0.0918	1.0000	0.0084	0.0909	OK
EYN	1F	10.33	2771.0068	387.9259	0.0552	1.0000	0.0069	0.0909	OK
RY(RS)	2F	10.99	1468.7744	233.6746	0.0779	1.0000	0.0081	0.0909	OK
RY(RS)	1F	10.33	2771.0068	317.3525	0.0457	1.0000	0.0070	0.0909	OK

Appendix 6. Capacity check for beams



Capacity in Beam(Random check)

1. Design Information

Member Number	:	22
Design Code	:	ACI318-05
Unit System	:	kips, ft
Material Data	:	fc = 432, fy = 8354.17, fys = 8354.17 ksf
Beam Span	:	16.7979 ft
Section Property	:	Beam (No : 2)

2. Section Diagram

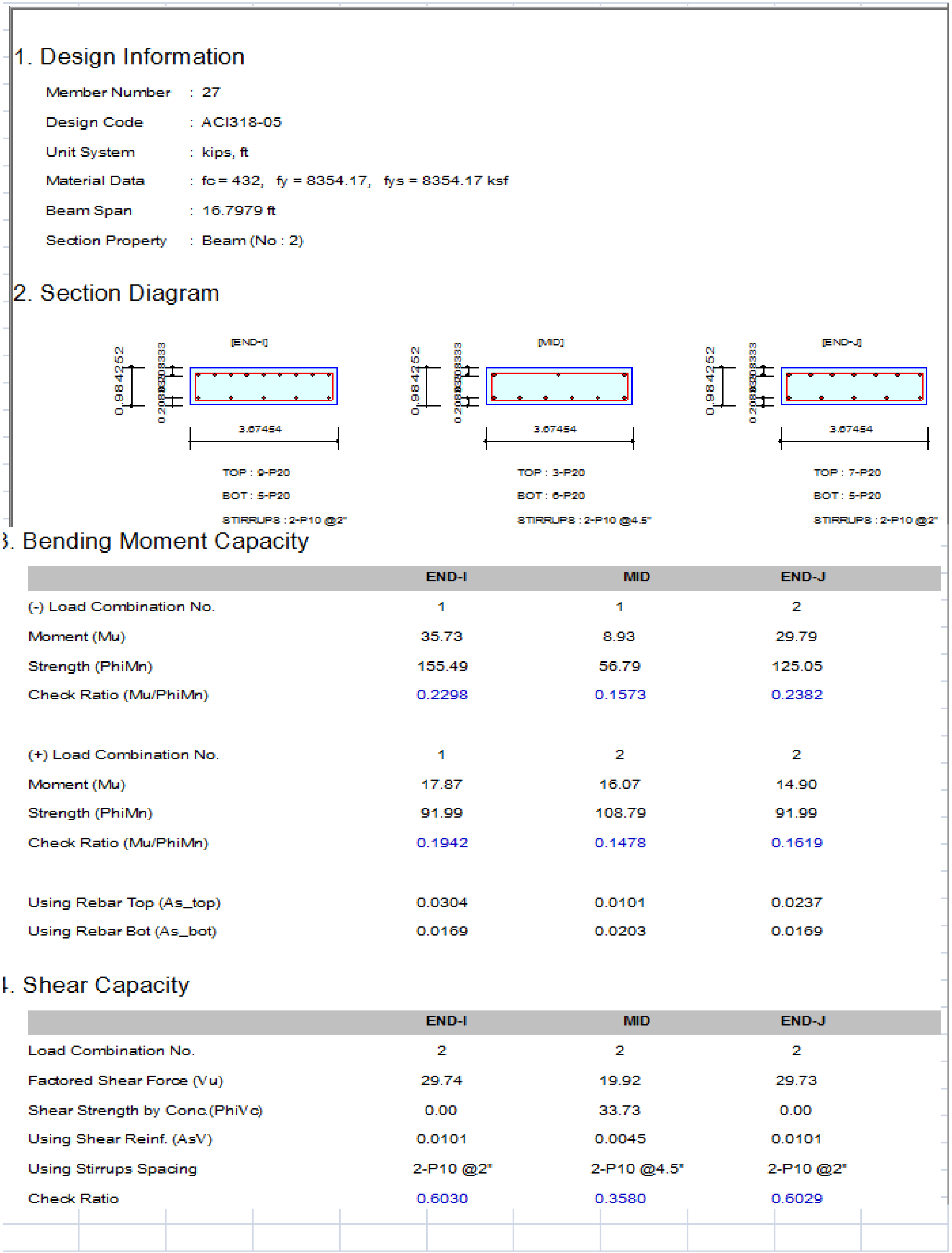
[END-I]	[MID]	[END-J]
TOP : 9-P20	TOP : 3-P20	TOP : 7-P20
BOT : 5-P20	BOT : 6-P20	BOT : 5-P20
STIRRUPS : 2-P10 @2"	STIRRUPS : 2-P10 @4.5"	STIRRUPS : 2-P10 @2"

3. Bending Moment Capacity

	END-I	MID	END-J
(-) Load Combination No.	1	1	2
Moment (Mu)	34.66	8.66	30.20
Strength (PhiMn)	155.49	56.79	125.05
Check Ratio (Mu/PhiMn)	0.2229	0.1526	0.2415
(+) Load Combination No.	1	2	2
Moment (Mu)	17.33	16.64	15.10
Strength (PhiMn)	91.99	108.79	91.99
Check Ratio (Mu/PhiMn)	0.1884	0.1530	0.1642
Using Rebar Top (As_top)	0.0304	0.0101	0.0237
Using Rebar Bot (As_bot)	0.0169	0.0203	0.0169

4. Shear Capacity

	END-I	MID	END-J
Load Combination No.	2	2	2
Factored Shear Force (Vu)	29.62	20.03	29.85
Shear Strength by Conc.(PhiVc)	0.00	33.73	0.00
Using Shear Reinf. (AsV)	0.0101	0.0045	0.0101
Using Stirrups Spacing	2-P10 @2"	2-P10 @4.5"	2-P10 @2"
Check Ratio	0.6006	0.3600	0.6052



1. Design Information

Member Number	: 27
Design Code	: ACI318-05
Unit System	: kips, ft
Material Data	: fc = 432, fy = 8354.17, fys = 8354.17 ksf
Beam Span	: 16.7979 ft
Section Property	: Beam (No : 2)

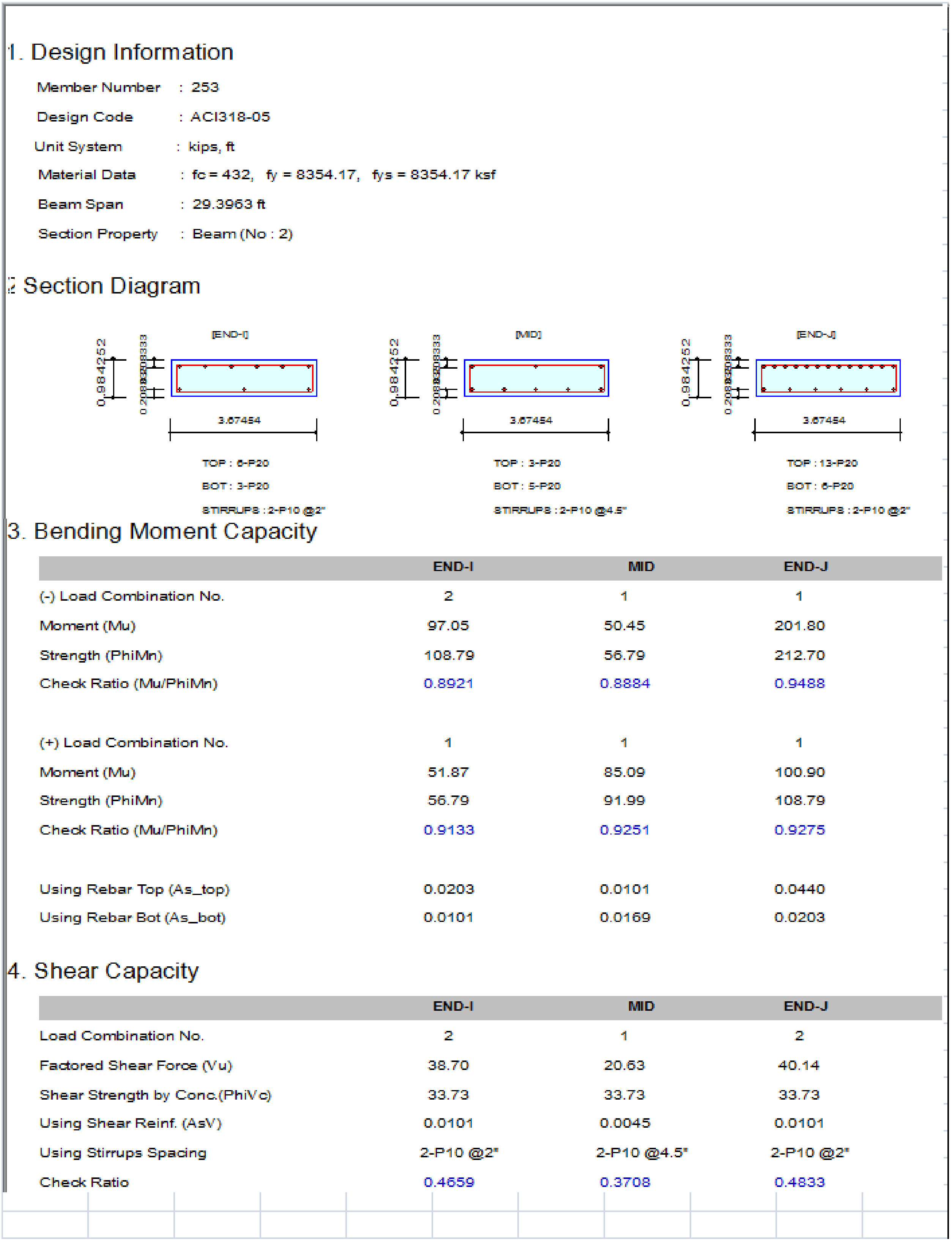
2. Section Diagram

3. Bending Moment Capacity

	END-I	MID	END-J
(-) Load Combination No.	1	1	2
Moment (Mu)	35.73	8.93	29.79
Strength (PhiMn)	155.49	56.79	125.05
Check Ratio (Mu/PhiMn)	0.2298	0.1573	0.2382
(+) Load Combination No.	1	2	2
Moment (Mu)	17.87	16.07	14.90
Strength (PhiMn)	91.99	108.79	91.99
Check Ratio (Mu/PhiMn)	0.1942	0.1478	0.1619
Using Rebar Top (As_top)	0.0304	0.0101	0.0237
Using Rebar Bot (As_bot)	0.0169	0.0203	0.0169

4. Shear Capacity

	END-I	MID	END-J
Load Combination No.	2	2	2
Factored Shear Force (Vu)	29.74	19.92	29.73
Shear Strength by Conc.(PhiVc)	0.00	33.73	0.00
Using Shear Reinf. (AsV)	0.0101	0.0045	0.0101
Using Stirrups Spacing	2-P10 @2"	2-P10 @4.5"	2-P10 @2"
Check Ratio	0.6030	0.3580	0.6029



1. Design Information

Member Number : 253

Design Code : ACI318-05

Unit System : kips, ft

Material Data : fc = 432, fy = 8354.17, fys = 8354.17 ksf

Beam Span : 29.3963 ft

Section Property : Beam (No : 2)

Section Diagram

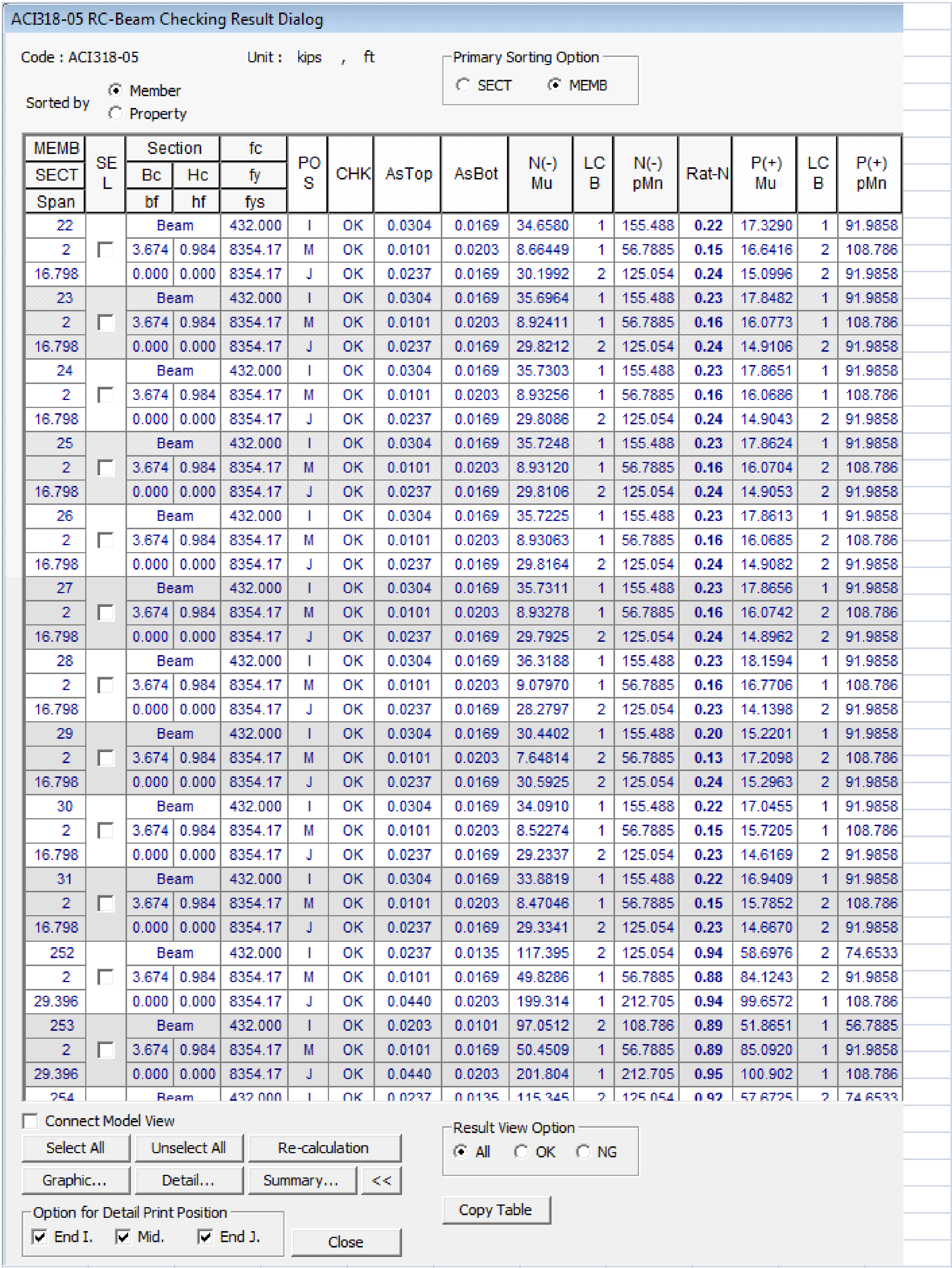
END-I	MID	END-J
TOP : 6-P20	TOP : 3-P20	TOP : 13-P20
BOT : 3-P20	BOT : 5-P20	BOT : 6-P20
STIRRUPS : 2-P10 @2"	STIRRUPS : 2-P10 @4.5"	STIRRUPS : 2-P10 @2"

3. Bending Moment Capacity

	END-I	MID	END-J
(-) Load Combination No.	2	1	1
Moment (Mu)	97.05	50.45	201.80
Strength (PhiMn)	108.79	56.79	212.70
Check Ratio (Mu/PhiMn)	0.8921	0.8884	0.9488
(+) Load Combination No.	1	1	1
Moment (Mu)	51.87	85.09	100.90
Strength (PhiMn)	56.79	91.99	108.79
Check Ratio (Mu/PhiMn)	0.9133	0.9251	0.9275
Using Rebar Top (As_top)	0.0203	0.0101	0.0440
Using Rebar Bot (As_bot)	0.0101	0.0169	0.0203

4. Shear Capacity

	END-I	MID	END-J
Load Combination No.	2	1	2
Factored Shear Force (Vu)	38.70	20.63	40.14
Shear Strength by Conc.(PhiVc)	33.73	33.73	33.73
Using Shear Reinf. (AsV)	0.0101	0.0045	0.0101
Using Stirrups Spacing	2-P10 @2"	2-P10 @4.5"	2-P10 @2"
Check Ratio	0.4659	0.3708	0.4833



Code : ACI318-05   Unit : kips , ft

Primary Sorting Option: ○ SECT ● MEMB

Sorted by: ● Member ○ Property

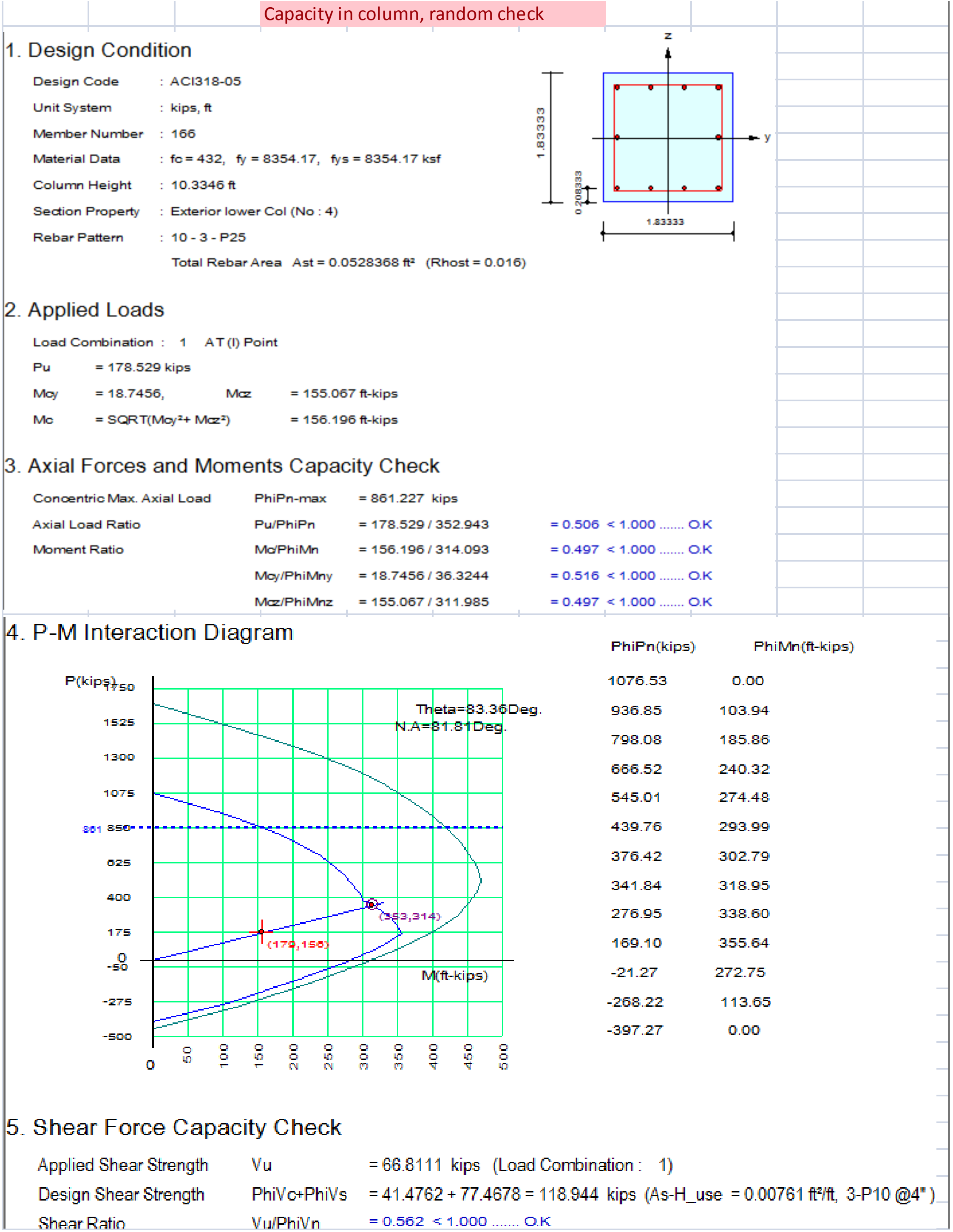
MEMB	SEL	Section		fc	POS	CHK	AsTop	AsBot	N(-) Mu	LCB	N(-) pMn	Rat-N	P(+) Mu	LCB	P(+) pMn
SECT		Bc	Hc	fy											
Span		bf	hf	fys											
22		Beam		432.000	I	OK	0.0304	0.0169	34.6580	1	155.488	**0.22**	17.3290	1	91.9858
2	☐	3.674	0.984	8354.17	M	OK	0.0101	0.0203	8.66449	1	56.7885	**0.15**	16.6416	2	108.786
16.798		0.000	0.000	8354.17	J	OK	0.0237	0.0169	30.1992	2	125.054	**0.24**	15.0996	2	91.9858
23		Beam		432.000	I	OK	0.0304	0.0169	35.6964	1	155.488	**0.23**	17.8482	1	91.9858
2	☐	3.674	0.984	8354.17	M	OK	0.0101	0.0203	8.92411	1	56.7885	**0.16**	16.0773	1	108.786
16.798		0.000	0.000	8354.17	J	OK	0.0237	0.0169	29.8212	2	125.054	**0.24**	14.9106	2	91.9858
24		Beam		432.000	I	OK	0.0304	0.0169	35.7303	1	155.488	**0.23**	17.8651	1	91.9858
2	☐	3.674	0.984	8354.17	M	OK	0.0101	0.0203	8.93256	1	56.7885	**0.16**	16.0686	1	108.786
16.798		0.000	0.000	8354.17	J	OK	0.0237	0.0169	29.8086	2	125.054	**0.24**	14.9043	2	91.9858
25		Beam		432.000	I	OK	0.0304	0.0169	35.7248	1	155.488	**0.23**	17.8624	1	91.9858
2	☐	3.674	0.984	8354.17	M	OK	0.0101	0.0203	8.93120	1	56.7885	**0.16**	16.0704	2	108.786
16.798		0.000	0.000	8354.17	J	OK	0.0237	0.0169	29.8106	2	125.054	**0.24**	14.9053	2	91.9858
26		Beam		432.000	I	OK	0.0304	0.0169	35.7225	1	155.488	**0.23**	17.8613	1	91.9858
2	☐	3.674	0.984	8354.17	M	OK	0.0101	0.0203	8.93063	1	56.7885	**0.16**	16.0685	2	108.786
16.798		0.000	0.000	8354.17	J	OK	0.0237	0.0169	29.8164	2	125.054	**0.24**	14.9082	2	91.9858
27		Beam		432.000	I	OK	0.0304	0.0169	35.7311	1	155.488	**0.23**	17.8656	1	91.9858
2	☐	3.674	0.984	8354.17	M	OK	0.0101	0.0203	8.93278	1	56.7885	**0.16**	16.0742	2	108.786
16.798		0.000	0.000	8354.17	J	OK	0.0237	0.0169	29.7925	2	125.054	**0.24**	14.8962	2	91.9858
28		Beam		432.000	I	OK	0.0304	0.0169	36.3188	1	155.488	**0.23**	18.1594	1	91.9858
2	☐	3.674	0.984	8354.17	M	OK	0.0101	0.0203	9.07970	1	56.7885	**0.16**	16.7706	1	108.786
16.798		0.000	0.000	8354.17	J	OK	0.0237	0.0169	28.2797	2	125.054	**0.23**	14.1398	2	91.9858
29		Beam		432.000	I	OK	0.0304	0.0169	30.4402	1	155.488	**0.20**	15.2201	1	91.9858
2	☐	3.674	0.984	8354.17	M	OK	0.0101	0.0203	7.64814	2	56.7885	**0.13**	17.2098	2	108.786
16.798		0.000	0.000	8354.17	J	OK	0.0237	0.0169	30.5925	2	125.054	**0.24**	15.2963	2	91.9858
30		Beam		432.000	I	OK	0.0304	0.0169	34.0910	1	155.488	**0.22**	17.0455	1	91.9858
2	☐	3.674	0.984	8354.17	M	OK	0.0101	0.0203	8.52274	1	56.7885	**0.15**	15.7205	1	108.786
16.798		0.000	0.000	8354.17	J	OK	0.0237	0.0169	29.2337	2	125.054	**0.23**	14.6169	2	91.9858
31		Beam		432.000	I	OK	0.0304	0.0169	33.8819	1	155.488	**0.22**	16.9409	1	91.9858
2	☐	3.674	0.984	8354.17	M	OK	0.0101	0.0203	8.47046	1	56.7885	**0.15**	15.7852	2	108.786
16.798		0.000	0.000	8354.17	J	OK	0.0237	0.0169	29.3341	2	125.054	**0.23**	14.6670	2	91.9858
252		Beam		432.000	I	OK	0.0237	0.0135	117.395	2	125.054	**0.94**	58.6976	2	74.6533
2	☐	3.674	0.984	8354.17	M	OK	0.0101	0.0169	49.8286	1	56.7885	**0.88**	84.1243	2	91.9858
29.396		0.000	0.000	8354.17	J	OK	0.0440	0.0203	199.314	1	212.705	**0.94**	99.6572	1	108.786
253		Beam		432.000	I	OK	0.0203	0.0101	97.0512	2	108.786	**0.89**	51.8651	1	56.7885
2	☐	3.674	0.984	8354.17	M	OK	0.0101	0.0169	50.4509	1	56.7885	**0.89**	85.0920	1	91.9858
29.396		0.000	0.000	8354.17	J	OK	0.0440	0.0203	201.804	1	212.705	**0.95**	100.902	1	108.786
254		Beam		432.000	I	OK	0.0237	0.0135	115.345	2	125.054	**0.92**	57.6725	2	74.6533

☐ Connect Model View

Result View Option: ● All ○ OK ○ NG

Option for Detail Print Position: ☑ End I. ☑ Mid. ☑ End J.

Appendix 7. Capacity check for Columns



Capacity in column, random check

1. Design Condition

Design Code : ACI318-05
Unit System : kips, ft
Member Number : 166
Material Data : fc = 432, fy = 8354.17, fys = 8354.17 ksf
Column Height : 10.3346 ft
Section Property : Exterior lower Col (No : 4)
Rebar Pattern : 10 - 3 - P25
Total Rebar Area Ast = 0.0528368 ft² (Rhost = 0.016)

2. Applied Loads

Load Combination : 1 AT (I) Point
Pu = 178.529 kips
Mcy = 18.7456, Mcz = 155.067 ft-kips
Mc = SQRT(Mcy²+ Mcz²) = 156.196 ft-kips

3. Axial Forces and Moments Capacity Check

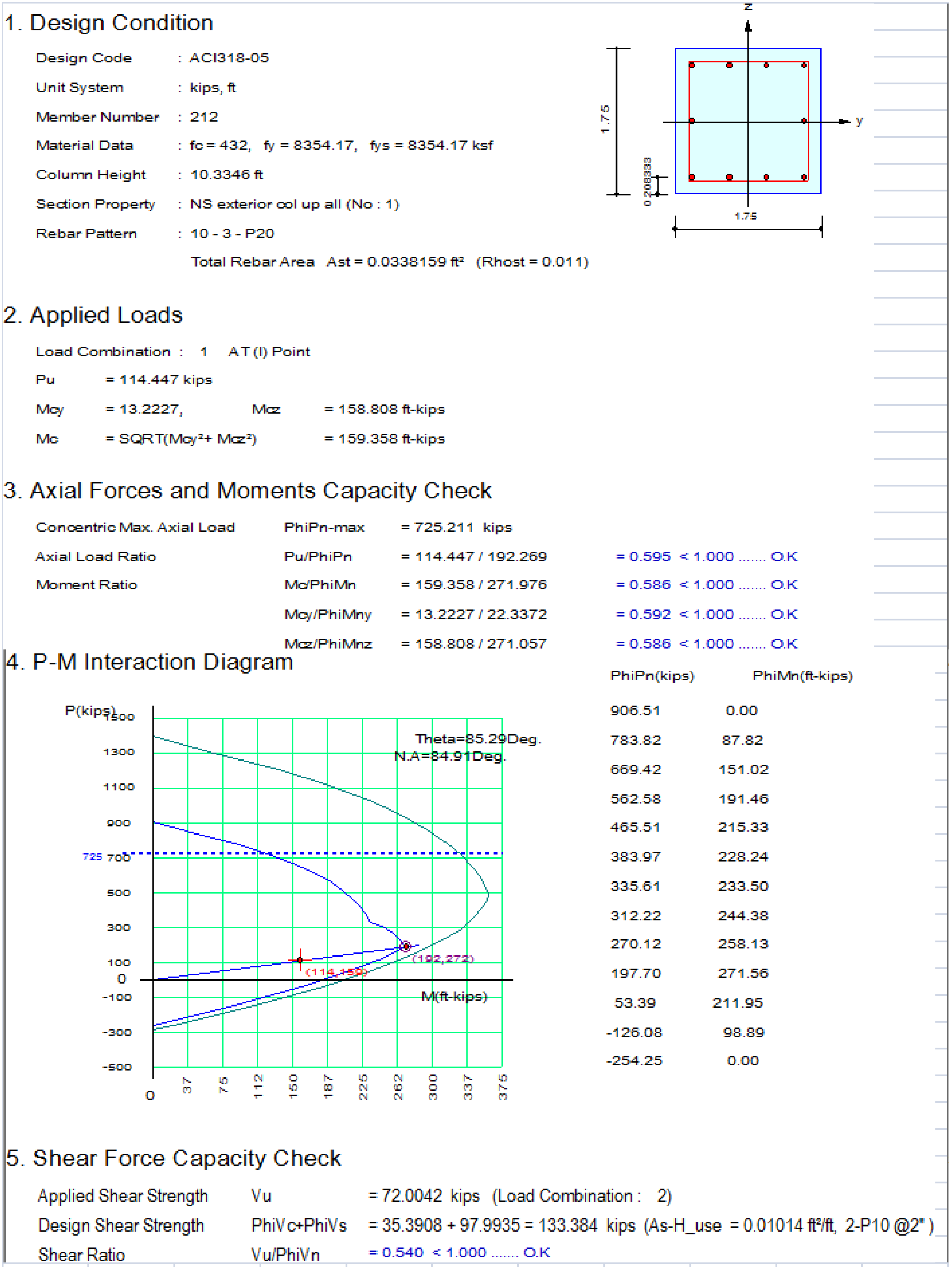
Concentric Max. Axial Load	PhiPn-max	= 861.227 kips	
Axial Load Ratio	Pu/PhiPn	= 178.529 / 352.943	= 0.506 < 1.000 .... O.K
Moment Ratio	Mc/PhiMn	= 156.196 / 314.093	= 0.497 < 1.000 .... O.K
	Mcy/PhiMny	= 18.7456 / 36.3244	= 0.516 < 1.000 .... O.K
	Mcz/PhiMnz	= 155.067 / 311.985	= 0.497 < 1.000 .... O.K

4. P-M Interaction Diagram

PhiPn(kips)	PhiMn(ft-kips)
1076.53	0.00
936.85	103.94
798.08	185.86
666.52	240.32
545.01	274.48
439.76	293.99
376.42	302.79
341.84	318.95
276.95	338.60
169.10	355.64
-21.27	272.75
-268.22	113.65
-397.27	0.00

5. Shear Force Capacity Check

Applied Shear Strength	Vu	= 66.8111 kips (Load Combination : 1)
Design Shear Strength	PhiVc+PhiVs	= 41.4762 + 77.4678 = 118.944 kips (As-H_use = 0.00761 ft²/ft, 3-P10 @4")
Shear Ratio	Vu/PhiVn	= 0.562 < 1.000 .... O.K



1. Design Condition

Design Code : ACI318-05

Unit System : kips, ft

Member Number : 212

Material Data : fc = 432, fy = 8354.17, fys = 8354.17 ksf

Column Height : 10.3346 ft

Section Property : NS exterior col up all (No : 1)

Rebar Pattern : 10 - 3 - P20

Total Rebar Area Ast = 0.0338159 ft² (Rhost = 0.011)

2. Applied Loads

Load Combination : 1 AT (I) Point

Pu = 114.447 kips

Mcy = 13.2227, Mcz = 158.808 ft-kips

Mc = SQRT(Mcy²+ Mcz²) = 159.358 ft-kips

3. Axial Forces and Moments Capacity Check

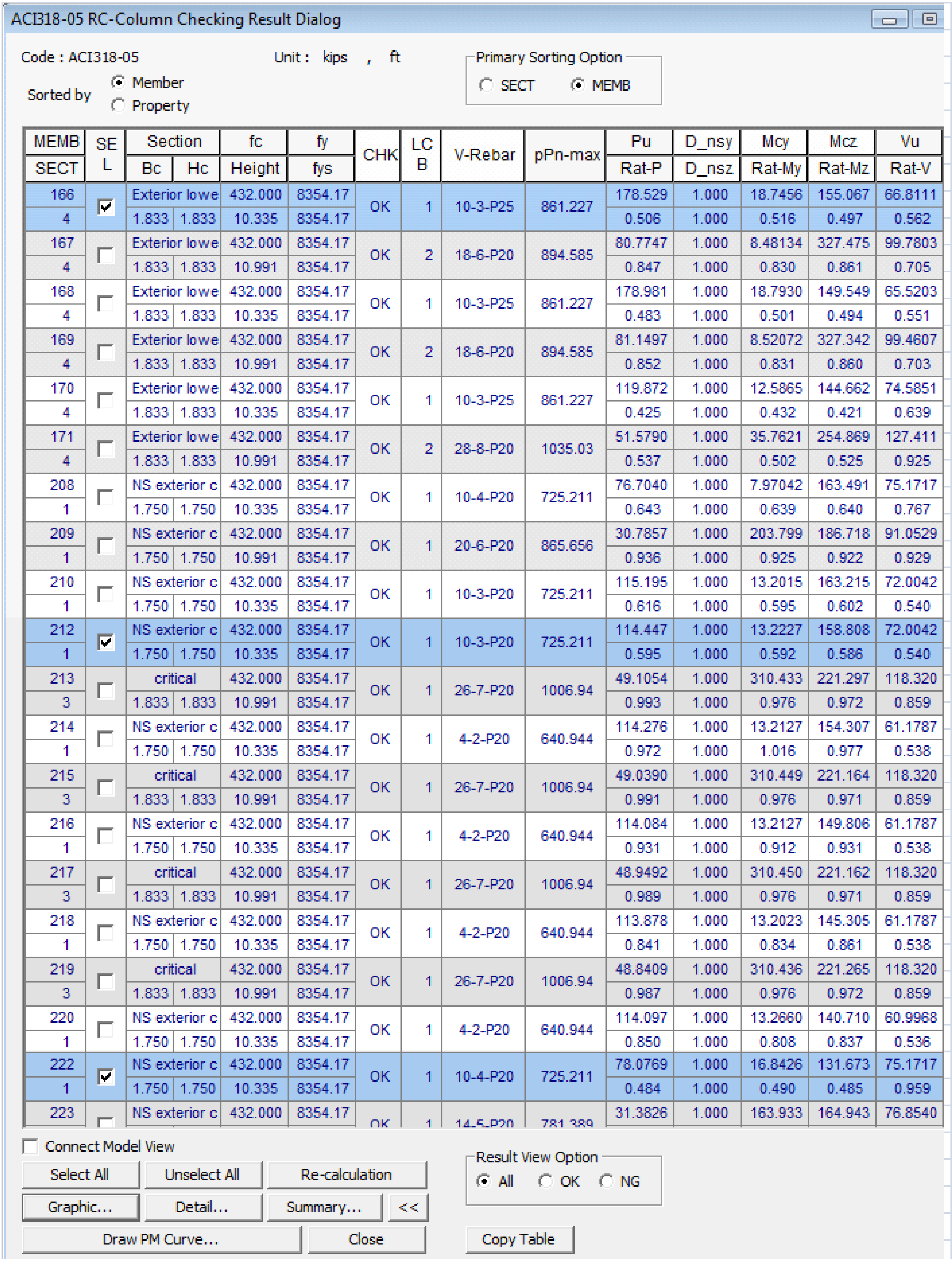
Concentric Max. Axial Load	PhiPn-max	= 725.211 kips	
Axial Load Ratio	Pu/PhiPn	= 114.447 / 192.269	= 0.595 < 1.000 .... O.K
Moment Ratio	Mc/PhiMn	= 159.358 / 271.976	= 0.586 < 1.000 .... O.K
	Mcy/PhiMny	= 13.2227 / 22.3372	= 0.592 < 1.000 .... O.K
	Mcz/PhiMnz	= 158.808 / 271.057	= 0.586 < 1.000 .... O.K

4. P-M Interaction Diagram

PhiPn(kips)	PhiMn(ft-kips)
906.51	0.00
783.82	87.82
669.42	151.02
562.58	191.46
465.51	215.33
383.97	228.24
335.61	233.50
312.22	244.38
270.12	258.13
197.70	271.56
53.39	211.95
-126.08	98.89
-254.25	0.00

5. Shear Force Capacity Check

Applied Shear Strength	Vu	= 72.0042 kips (Load Combination : 2)
Design Shear Strength	PhiVc+PhiVs	= 35.3908 + 97.9935 = 133.384 kips (As-H_use = 0.01014 ft²/ft, 2-P10 @2")
Shear Ratio	Vu/PhiVn	= 0.540 < 1.000 .... O.K



ACI318-05 RC-Column Checking Result Dialog

Code : ACI318-05

Unit : kips , ft

Sorted by ● Member ○ Property

Primary Sorting Option ○ SECT ● MEMB

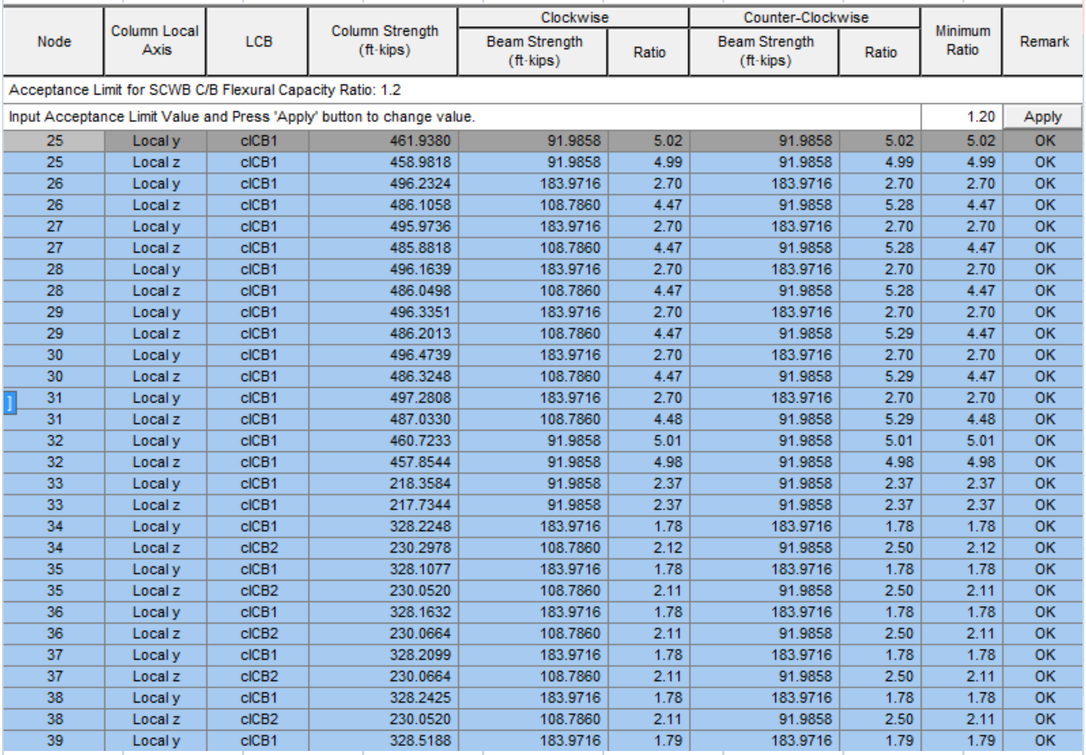
MEMB	SEL	Section		fc	fy	CHK	LCB	V-Rebar	pPn-max	Pu	D_nsy	Mcy	Mcz	Vu
SECT		Bc	Hc	Height	fys					Rat-P	D_nsz	Rat-My	Rat-Mz	Rat-V
166	☑	Exterior lowe		432.000	8354.17	OK	1	10-3-P25	861.227	178.529	1.000	18.7456	155.067	66.8111
4		1.833	1.833	10.335	8354.17					0.506	1.000	0.516	0.497	0.562
167	☐	Exterior lowe		432.000	8354.17	OK	2	18-6-P20	894.585	80.7747	1.000	8.48134	327.475	99.7803
4		1.833	1.833	10.991	8354.17					0.847	1.000	0.830	0.861	0.705
168	☐	Exterior lowe		432.000	8354.17	OK	1	10-3-P25	861.227	178.981	1.000	18.7930	149.549	65.5203
4		1.833	1.833	10.335	8354.17					0.483	1.000	0.501	0.494	0.551
169	☐	Exterior lowe		432.000	8354.17	OK	2	18-6-P20	894.585	81.1497	1.000	8.52072	327.342	99.4607
4		1.833	1.833	10.991	8354.17					0.852	1.000	0.831	0.860	0.703
170	☐	Exterior lowe		432.000	8354.17	OK	1	10-3-P25	861.227	119.872	1.000	12.5865	144.662	74.5851
4		1.833	1.833	10.335	8354.17					0.425	1.000	0.432	0.421	0.639
171	☐	Exterior lowe		432.000	8354.17	OK	2	28-8-P20	1035.03	51.5790	1.000	35.7621	254.869	127.411
4		1.833	1.833	10.991	8354.17					0.537	1.000	0.502	0.525	0.925
208	☐	NS exterior c		432.000	8354.17	OK	1	10-4-P20	725.211	76.7040	1.000	7.97042	163.491	75.1717
1		1.750	1.750	10.335	8354.17					0.643	1.000	0.639	0.640	0.767
209	☐	NS exterior c		432.000	8354.17	OK	1	20-6-P20	865.656	30.7857	1.000	203.799	186.718	91.0529
1		1.750	1.750	10.991	8354.17					0.936	1.000	0.925	0.922	0.929
210	☐	NS exterior c		432.000	8354.17	OK	1	10-3-P20	725.211	115.195	1.000	13.2015	163.215	72.0042
1		1.750	1.750	10.335	8354.17					0.616	1.000	0.595	0.602	0.540
212	☑	NS exterior c		432.000	8354.17	OK	1	10-3-P20	725.211	114.447	1.000	13.2227	158.808	72.0042
1		1.750	1.750	10.335	8354.17					0.595	1.000	0.592	0.586	0.540
213	☐	critical		432.000	8354.17	OK	1	26-7-P20	1006.94	49.1054	1.000	310.433	221.297	118.320
3		1.833	1.833	10.991	8354.17					0.993	1.000	0.976	0.972	0.859
214	☐	NS exterior c		432.000	8354.17	OK	1	4-2-P20	640.944	114.276	1.000	13.2127	154.307	61.1787
1		1.750	1.750	10.335	8354.17					0.972	1.000	1.016	0.977	0.538
215	☐	critical		432.000	8354.17	OK	1	26-7-P20	1006.94	49.0390	1.000	310.449	221.164	118.320
3		1.833	1.833	10.991	8354.17					0.991	1.000	0.976	0.971	0.859
216	☐	NS exterior c		432.000	8354.17	OK	1	4-2-P20	640.944	114.084	1.000	13.2127	149.806	61.1787
1		1.750	1.750	10.335	8354.17					0.931	1.000	0.912	0.931	0.538
217	☐	critical		432.000	8354.17	OK	1	26-7-P20	1006.94	48.9492	1.000	310.450	221.162	118.320
3		1.833	1.833	10.991	8354.17					0.989	1.000	0.976	0.971	0.859
218	☐	NS exterior c		432.000	8354.17	OK	1	4-2-P20	640.944	113.878	1.000	13.2023	145.305	61.1787
1		1.750	1.750	10.335	8354.17					0.841	1.000	0.834	0.861	0.538
219	☐	critical		432.000	8354.17	OK	1	26-7-P20	1006.94	48.8409	1.000	310.436	221.265	118.320
3		1.833	1.833	10.991	8354.17					0.987	1.000	0.976	0.972	0.859
220	☐	NS exterior c		432.000	8354.17	OK	1	4-2-P20	640.944	114.097	1.000	13.2660	140.710	60.9968
1		1.750	1.750	10.335	8354.17					0.850	1.000	0.808	0.837	0.536
222	☑	NS exterior c		432.000	8354.17	OK	1	10-4-P20	725.211	78.0769	1.000	16.8426	131.673	75.1717
1		1.750	1.750	10.335	8354.17					0.484	1.000	0.490	0.485	0.959
223	☐	NS exterior c		432.000	8354.17	OK	1	14-5-P20	781.389	31.3826	1.000	163.933	164.943	76.8540

☐ Connect Model View

Result View Option ● All ○ OK ○ NG

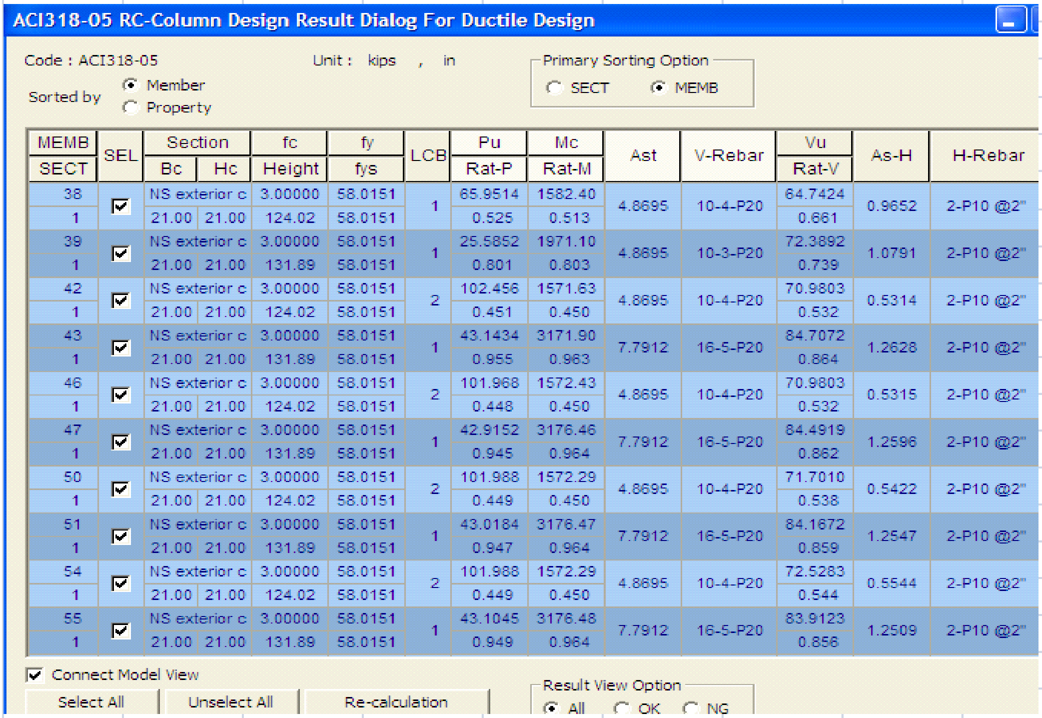
Appendix 8. Strong Column-Weak Beam Check

Strong column-Weak beam Check



Node	Column Local Axis	LCB	Column Strength (ft·kips)	Clockwise		Counter-Clockwise		Minimum Ratio	Remark
				Beam Strength (ft·kips)	Ratio	Beam Strength (ft·kips)	Ratio		
Acceptance Limit for SCWB C/B Flexural Capacity Ratio: 1.2									
Input Acceptance Limit Value and Press 'Apply' button to change value.								1.20	Apply
25	Local y	clCB1	461.9380	91.9858	5.02	91.9858	5.02	5.02	OK
25	Local z	clCB1	458.9818	91.9858	4.99	91.9858	4.99	4.99	OK
26	Local y	clCB1	496.2324	183.9716	2.70	183.9716	2.70	2.70	OK
26	Local z	clCB1	486.1058	108.7860	4.47	91.9858	5.28	4.47	OK
27	Local y	clCB1	495.9736	183.9716	2.70	183.9716	2.70	2.70	OK
27	Local z	clCB1	485.8818	108.7860	4.47	91.9858	5.28	4.47	OK
28	Local y	clCB1	496.1639	183.9716	2.70	183.9716	2.70	2.70	OK
28	Local z	clCB1	486.0498	108.7860	4.47	91.9858	5.28	4.47	OK
29	Local y	clCB1	496.3351	183.9716	2.70	183.9716	2.70	2.70	OK
29	Local z	clCB1	486.2013	108.7860	4.47	91.9858	5.29	4.47	OK
30	Local y	clCB1	496.4739	183.9716	2.70	183.9716	2.70	2.70	OK
30	Local z	clCB1	486.3248	108.7860	4.47	91.9858	5.29	4.47	OK
31	Local y	clCB1	497.2808	183.9716	2.70	183.9716	2.70	2.70	OK
31	Local z	clCB1	487.0330	108.7860	4.48	91.9858	5.29	4.48	OK
32	Local y	clCB1	460.7233	91.9858	5.01	91.9858	5.01	5.01	OK
32	Local z	clCB1	457.8544	91.9858	4.98	91.9858	4.98	4.98	OK
33	Local y	clCB1	218.3584	91.9858	2.37	91.9858	2.37	2.37	OK
33	Local z	clCB1	217.7344	91.9858	2.37	91.9858	2.37	2.37	OK
34	Local y	clCB1	328.2248	183.9716	1.78	183.9716	1.78	1.78	OK
34	Local z	clCB2	230.2978	108.7860	2.12	91.9858	2.50	2.12	OK
35	Local y	clCB1	328.1077	183.9716	1.78	183.9716	1.78	1.78	OK
35	Local z	clCB2	230.0520	108.7860	2.11	91.9858	2.50	2.11	OK
36	Local y	clCB1	328.1632	183.9716	1.78	183.9716	1.78	1.78	OK
36	Local z	clCB2	230.0664	108.7860	2.11	91.9858	2.50	2.11	OK
37	Local y	clCB1	328.2099	183.9716	1.78	183.9716	1.78	1.78	OK
37	Local z	clCB2	230.0664	108.7860	2.11	91.9858	2.50	2.11	OK
38	Local y	clCB1	328.2425	183.9716	1.78	183.9716	1.78	1.78	OK
38	Local z	clCB2	230.0520	108.7860	2.11	91.9858	2.50	2.11	OK
39	Local y	clCB1	328.5188	183.9716	1.79	183.9716	1.79	1.79	OK

Ductile design Check



ACI318-05 RC-Column Design Result Dialog For Ductile Design

Code : ACI318-05

Unit : kips , in

Sorted by ● Member ○ Property

Primary Sorting Option ○ SECT ● MEMB

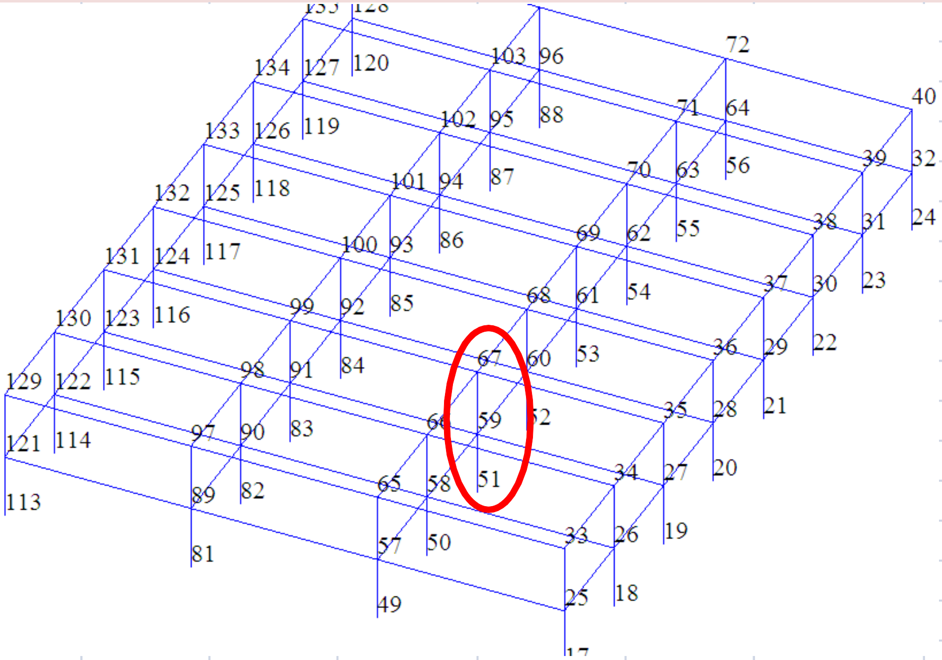
MEMB	SEL	Section		fc	fy	LCB	Pu	Mc	Ast	V-Rebar	Vu	As-H	H-Rebar
SECT		Bc	Hc	Height	fys		Rat-P	Rat-M			Rat-V		
38	☑	NS exterior c		3.00000	58.0151	1	65.9514	1582.40	4.8695	10-4-P20	64.7424	0.9652	2-P10 @2"
1		21.00	21.00	124.02	58.0151		0.525	0.513			0.661		
39	☑	NS exterior c		3.00000	58.0151	1	25.5852	1971.10	4.8695	10-3-P20	72.3892	1.0791	2-P10 @2"
1		21.00	21.00	131.89	58.0151		0.801	0.803			0.739		
42	☑	NS exterior c		3.00000	58.0151	2	102.456	1571.63	4.8695	10-4-P20	70.9803	0.5314	2-P10 @2"
1		21.00	21.00	124.02	58.0151		0.451	0.450			0.532		
43	☑	NS exterior c		3.00000	58.0151	1	43.1434	3171.90	7.7912	16-5-P20	84.7072	1.2628	2-P10 @2"
1		21.00	21.00	131.89	58.0151		0.955	0.963			0.864		
46	☑	NS exterior c		3.00000	58.0151	2	101.968	1572.43	4.8695	10-4-P20	70.9803	0.5315	2-P10 @2"
1		21.00	21.00	124.02	58.0151		0.448	0.450			0.532		
47	☑	NS exterior c		3.00000	58.0151	1	42.9152	3176.46	7.7912	16-5-P20	84.4919	1.2596	2-P10 @2"
1		21.00	21.00	131.89	58.0151		0.945	0.964			0.862		
50	☑	NS exterior c		3.00000	58.0151	2	101.988	1572.29	4.8695	10-4-P20	71.7010	0.5422	2-P10 @2"
1		21.00	21.00	124.02	58.0151		0.449	0.450			0.538		
51	☑	NS exterior c		3.00000	58.0151	1	43.0184	3176.47	7.7912	16-5-P20	84.1672	1.2547	2-P10 @2"
1		21.00	21.00	131.89	58.0151		0.947	0.964			0.859		
54	☑	NS exterior c		3.00000	58.0151	2	101.988	1572.29	4.8695	10-4-P20	72.5283	0.5544	2-P10 @2"
1		21.00	21.00	124.02	58.0151		0.449	0.450			0.544		
55	☑	NS exterior c		3.00000	58.0151	1	43.1045	3176.48	7.7912	16-5-P20	83.9123	1.2509	2-P10 @2"
1		21.00	21.00	131.89	58.0151		0.949	0.964			0.856		

☑ Connect Model View

Result View Option ● All ○ OK ○ NG

Strong Col-Weak Beam concept			Reference	
?Mn$_{col}$	$\geq$	1.2?Mn$_{b}$	ACI	21.4.2.2

Hand Calculation checking



Node	Axis	load	Mncol(kft)	Cw Mnb(kft)	Ratio	Ccw Mnc(kft)	Ratio	min Ratio
67	Local z	clCB2	439	234	1.88	303	1.45	1.45
59	Local z	clCB1	675	234	2.88	303	2.22	2.22

Node	min Ratio		Need		Check
67	1.45	>	1.2	=	OK
59	2.22	>	1.2	=	OK